THE STATE OF SCIENCE 2023

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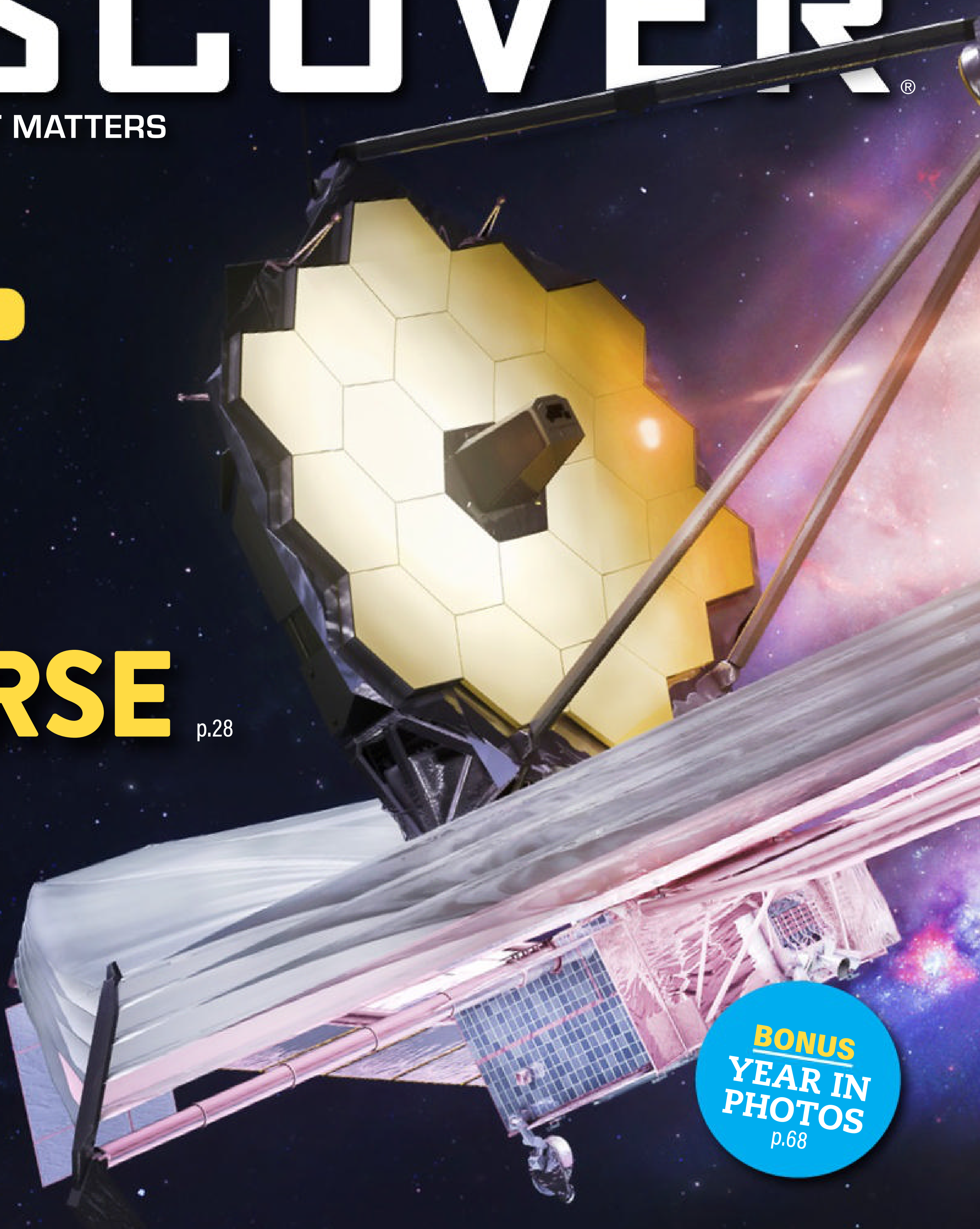

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CLOCKWISE FROM TOP LEFT: MIA STUDIO/SHUTTERSTOCK; LJOBSY/SHUTTERSTOCK; PAUL BAKER/FRIENDS OF DINOSAUR VALLEY

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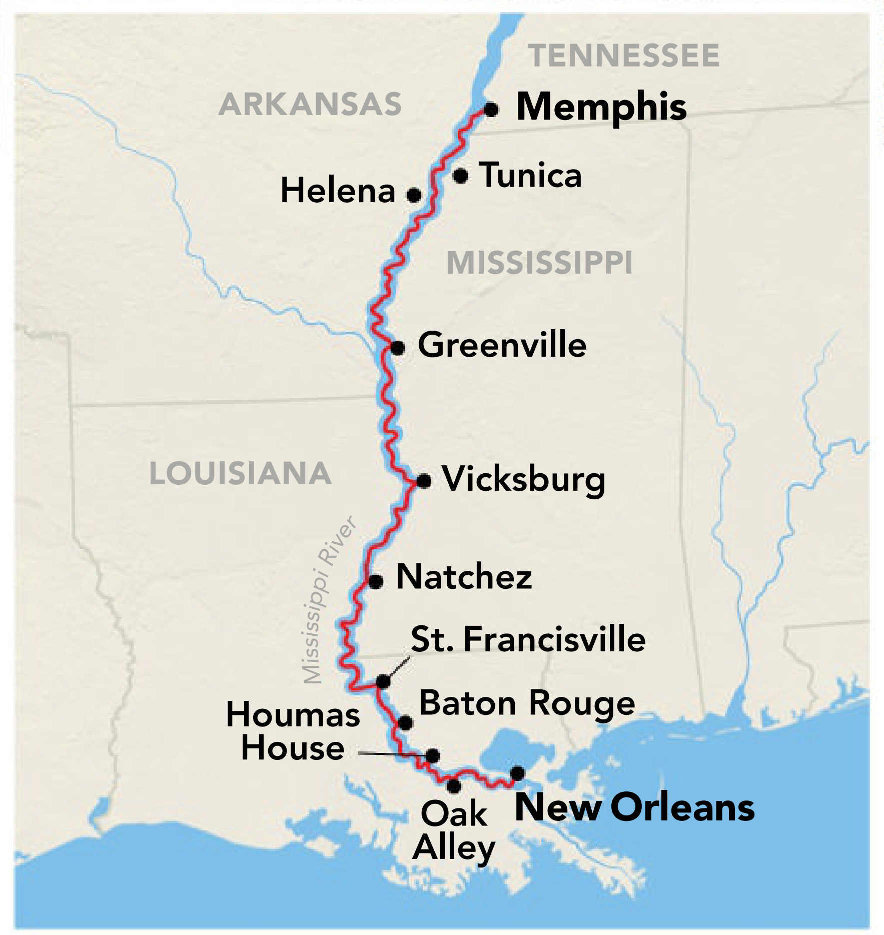
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BY STEPHEN C. GEORGE

Mind the Gap

EVERY YEAR, it's something. Often, it's several somethings. As the *Discover* team gathers material to fill this issue, our annual round-up of the biggest science stories of the year, it always comes to pass that some big science stories never make it into these pages. Sometimes, that's simply the result of space constraints, when we're forced to make difficult decisions about what stays and what goes.

Often, a great story doesn't get play in these pages thanks to the vagaries of time or even the weather. Take NASA's Artemis mission, the test flight that will send a new craft to the moon and back, in anticipation of future manned missions and the eventual return of humans to the lunar surface after more than 50 years away. I really wanted a story about it in this issue, or at least a dramatic photo of that first launch, originally scheduled for Aug. 29. As I write this, the launch has been delayed twice (once because of Hurricane Ian) and we're eagerly anticipating an update — and hopefully confirmation — that liftoff will finally happen on Nov. 14, about the time we're hustling to get this issue to the printer.

It is the perennial frustration of working in the print medium: that we can never be a timely as we might wish. Even an issue like this, by far our most popular and informative, is subject to a gap of time between when we go to press and when you see it. And during that period of time, amazing new science stories are all but guaranteed to develop.

Of course, we can fill that void much more easily than in the pre-digital era. Every day we post new stories on DiscoverMagazine.com, and that's where you can always go to read about the latest scientific discoveries. But I'm especially mindful of that gap when I ask our loyal and attentive readers my annual question (at right).

Thanks, and enjoy the issue!

Stephen C. George, Editorial Director

Feel free to send comments and questions to

editorial@discovermagazine.com

What was the biggest science story of the year for you? I'm especially interested in stories that you don't see in the pages that follow. We'll be sure to call those out when we feature some of your answers in a future issue. Email me at editorial@discovermagazine.com and let me know.

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STEPHEN C. GEORGE Editorial Director
ELIZABETH M. WEBER Design Director

EDITORIAL
TREE MEINCH Features Editor
ELISA R. NECKAR Senior Production Editor
ALEX ORLANDO Associate Editor
MARISA SLOAN Assistant Editor
SAM WALTERS Assistant Editor
SAMANTHA HILL Editorial Assistant
JASON P. DINH AAAS Mass Media Fellow

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MONICA CULL Assistant Digital Editor

CONTRIBUTORS
BRIDGET ALEX, GABRIEL ALLEN, RILEY BLACK,KATE GOLEMBIEWSKI, AVERY HURT, ERIK KLEMETTI, EMILIE LUCCHESI, KENNETH MILLER, STEVE NADIS, SARA NOVAK, JOSHUA RAPP LEARN, ELIZABETH SVOBODA, TOM YULSMAN, SCISTARTER, DARLENE CAVALIER (special projects)

ADVERTISING
KRISTI RUMMEL Advertising Representative
608 435 6220
krummel@kalmbach.com

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Customer Service: customerservice@DiscoverMagazine.info

EDITORIAL INQUIRIES
editorial@discovermagazine.com
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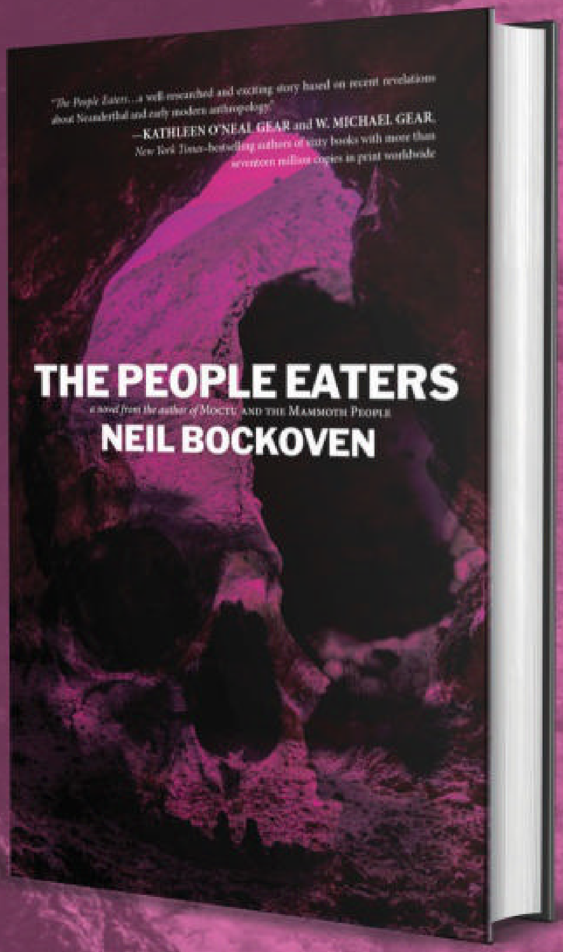
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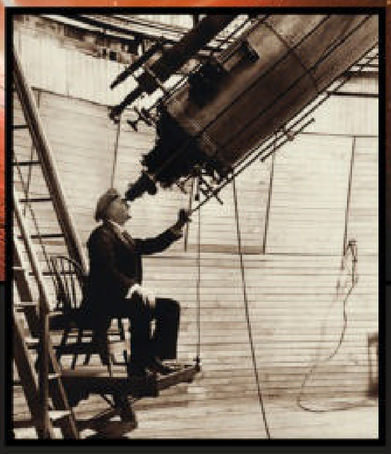

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REDEFINING SUICIDE

THE VALUE OF HOPE

("Redefining Suicide," Jul/Aug 2022)

As a retired psychiatric nurse practitioner, I read "Redefining Suicide" with great interest. It defined the problem clearly and offered practical information on suicide prevention. However, all of the people quoted in the article failed to mention one thing that I consider of paramount importance in reducing suicide risk: the instillation of hope. Suicide contracts don't work if no hope is offered. When I was practicing, I had very frank conversations with my patients regarding suicide, specifically impulsivity. When I contracted with my patients, I always tried to offer them hope, reassuring them that I would be with them on their journey and that I was not going to give up trying to help them, and they should not give up either. Offering hope that life can be different, that they can be different and that someone will be there with them can be powerful medicine.

Linda Lazzari

THE COST OF HEALTH AI

("AI in Medicine," Jul/Aug 2022)

While I am hoping AI will help medical providers in diagnosing and treating patients, two problems I foresee involve insurance companies. One is that if AI flags a person [who may have] a disease years into the future, insurance companies may refuse to insure that person. The other is that, at present, insurance companies will not pay on a claim unless it is diagnosed or is a procedure performed by an in-person medical provider. Insurance companies are in the business of wealth, not health. They want to collect premiums for years, hoping never to pay out on a claim. We have a long way to go before AI is the standard.

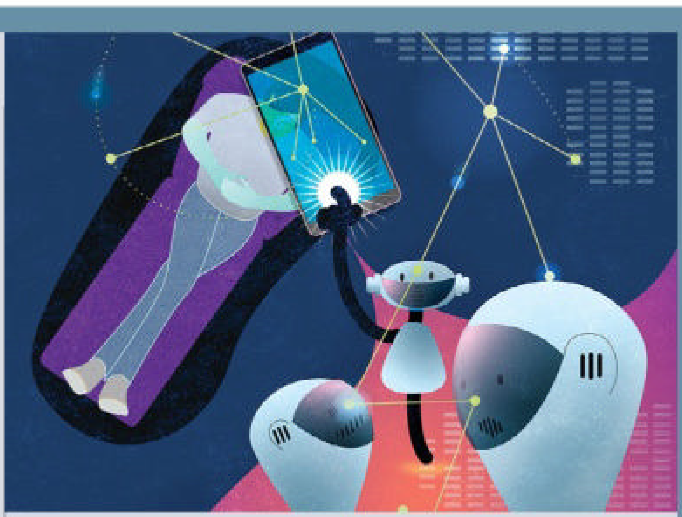
Hope LeVeck

AI AIDE

("A Closer Look," Jul/Aug 2022)

As I read "A Closer Look," I focused on the idea that doctors would accept machine prediction as an aid to their own clinical expertise in detecting such threats as breast cancer. All well and good, but as the machinery becomes more sophisticated, the doctor corps will age out and turn over to the next generation that has not developed its own clinical expertise. Might the future then be one of increasing reliance on machinery at the expense of human experience?

Stuart Lynn



LOOK FAMILIAR?

("The Creepy Feeling of the Uncanny Valley," Jul/Aug 2022)

While this article discusses robots, it is a reminder of how we think of space aliens as well. Why do we think of either as some weird version of ourselves? Are we that arrogant? Of all the matter in the cosmos, we can only touch, feel, smell, hear, or see about 5 percent; 95 percent consists of dark matter and dark energy. So, why can't we imagine space aliens, or robots, as appearing far different than ourselves? Why must they have bodies, arms, legs, feet, and heads like us? Why can't we come up with imaginative ideas of really weird creatures?

Ed Yrisarri

STICKER SHOCK

("Catching Wind," May/Jun 2022)

Your article about wind power does not take into account the economics of the situation: everything from the costs and availability of the required structural supplies (steel, concrete, rare earth metals, etc.), to the need for 100 percent backup to account for slack in wind times, to the (so far) unobtainable battery backup requirements. This would dictate that massive, utility-grade wind power is just not practical.

Tom Portante

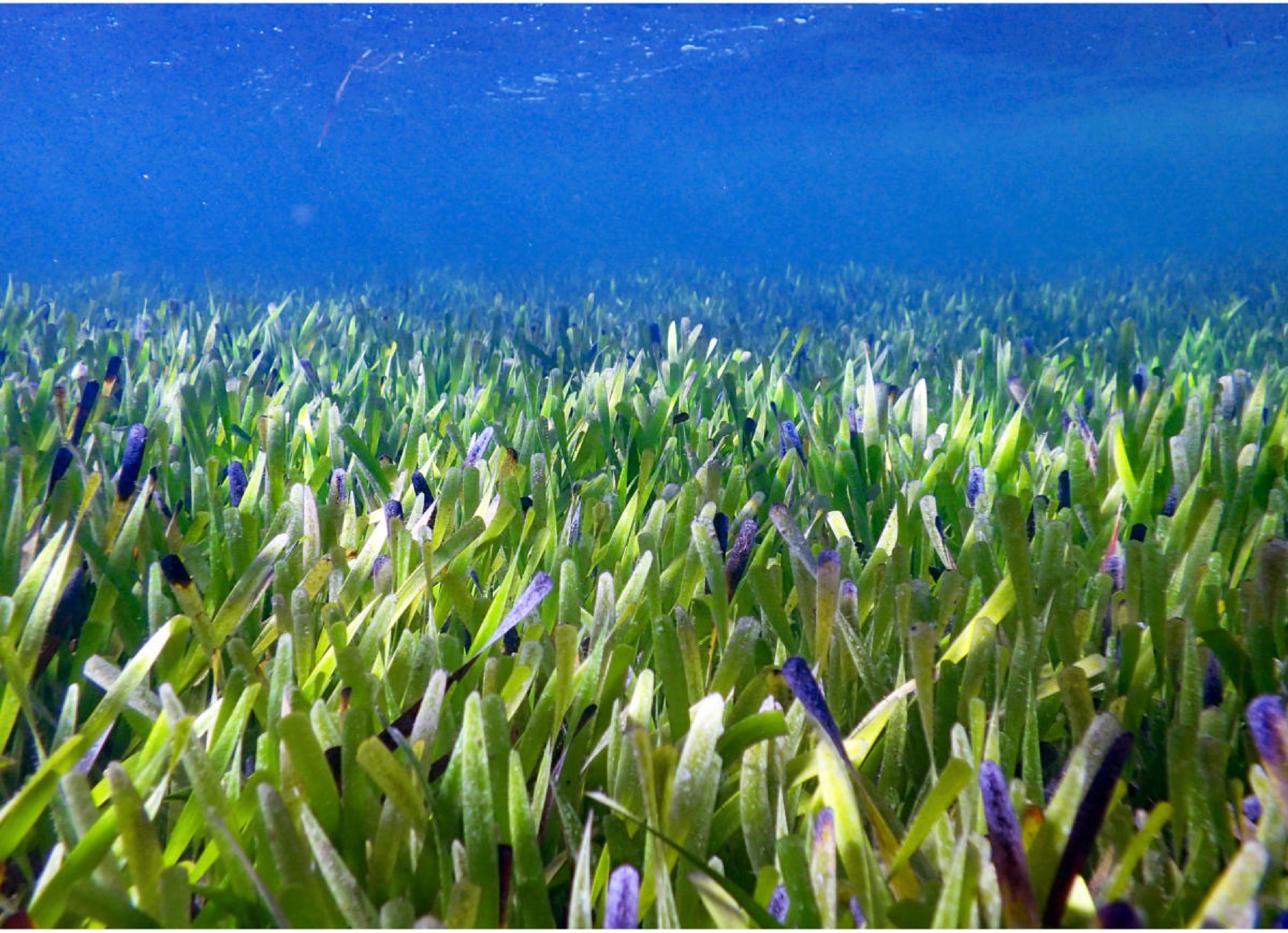
FEATURES EDITOR TREE MEINCH RESPONDS: *Thanks for reading, Tom! It sounds like you're interested in the life-cycle assessment (or LCA) of a wind turbine, which is any product's total pollution output or carbon footprint — considering its manufacturing process, disposal at the end of its life and everything in between.*

A 2019 comprehensive scientific review of the LCA of wind turbines showed that an average turbine in the U.S. will generate 3.4 times the amount of energy that it cost to create it within 20 years. The average lifespan of turbines is between 20 and 25 years, with some lasting much longer, especially as design advances. Hope that helps address your concerns.

ILLUSTRATION: KELLIE JAEGER/DISCOVER. ROBOT PHOTO, BOTTOM: HIROSHI ISHIGURO LABORATORY/ATR

THE LATEST NEWS AND NOTES

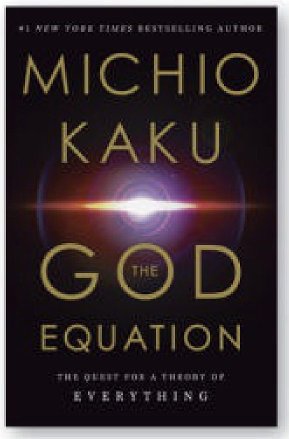
Q&A WITH MICHIO KAKU • HUMANS AND NEANDERTHALS SHARED THIS CAVE • GEESE IN LOVE? • PULLING DNA OUT OF THE AIR • HOW LONELINESS EVOLVED • WATERLOO REMAINS



RECORD-SHATTERING SEAGRASS

Believe it or not, this sliver of an underwater seagrass pasture is all part of the same plant. In fact, scientists have declared it the largest single organism alive today, according to a study published in *Proceedings of the Royal Society B* in June. (It seized the Guinness World Record from a 4-square-mile mushroom in Oregon, affectionately dubbed the Humongous Fungus.) The seagrass, called Poseidon's ribbon weed, or *Posidonia australis*, resides in Western Australia's Shark Bay and stretches across 77 square miles — over three times larger than Manhattan. The plant germinated from a single seed 4,500 years ago and has been sprouting clonal offshoots ever since. —JASON P. DINH; IMAGE BY RACHEL AUSTIN/UNIVERSITY OF WESTERN AUSTRALIA

Q+A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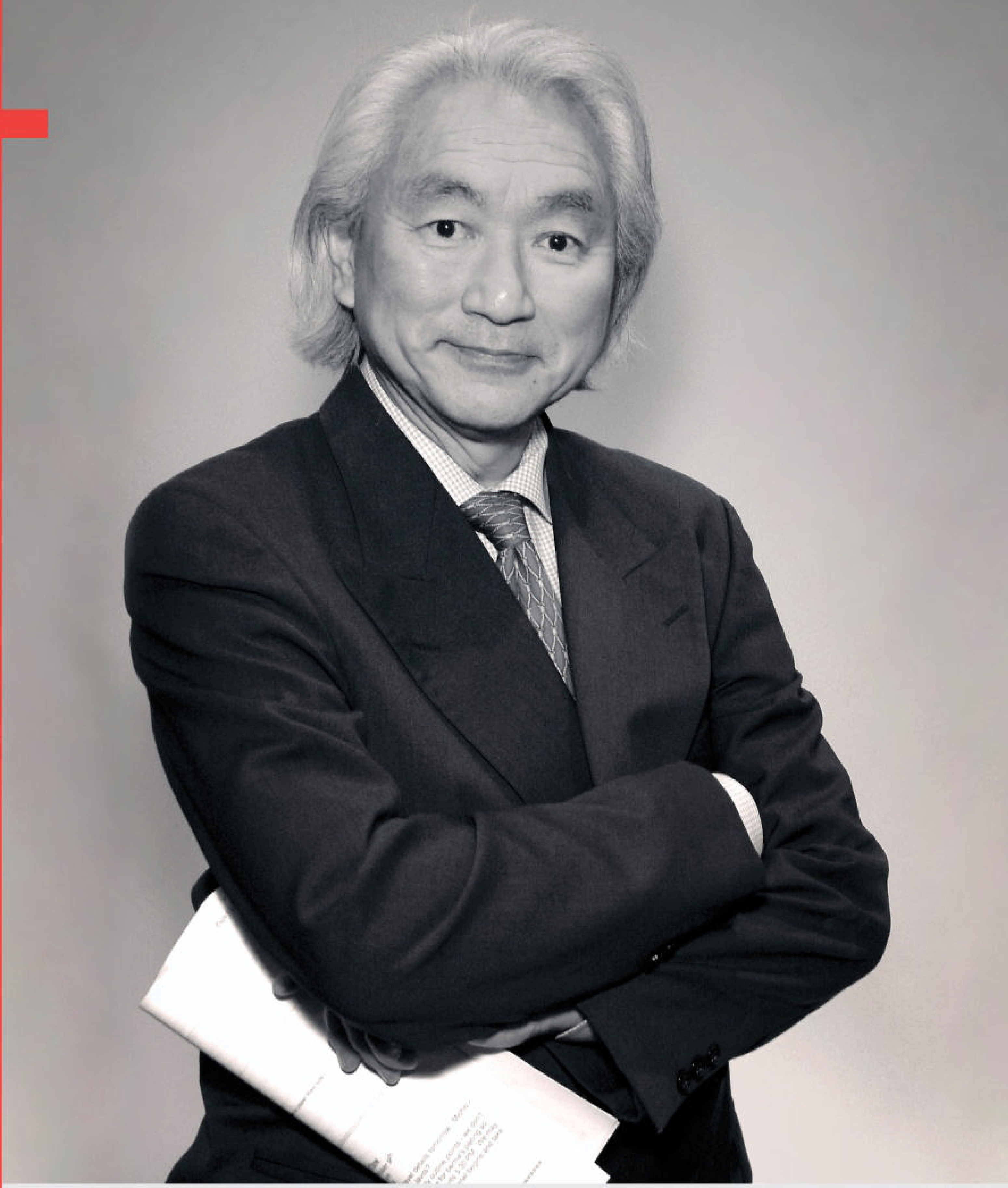
THE QUEST FOR A THEORY OF EVERYTHING

THE THEORETICAL PHYSICIST TALKS ABOUT THE BOOK THAT ALBERT EINSTEIN COULDN'T FINISH, HIS FAVORITE SCI-FI UNIVERSE AND THE LONG-SOUGHT EFFORT TO UNITE THE FORCES OF NATURE IN A SINGLE EQUATION.



Michio Kaku's Lifelong Quest

Even with a smartphone and Google at your fingertips, some things are just hard to wrap your brain around. Take, for example, the seemingly improbable idea that energy does not flow continuously, but is released in discrete packets called quanta. Or the mind-numbing notion that the entirety of the cosmos, spanning some 93 billion light-years across, may be just one in a multitude of parallel universes.

That's where Michio Kaku comes in. The theoretical physicist has built a robust secondary career as a mass-market science popularizer, untangling some of physics' knottiest concepts and streamlining them for the public. His latest book, *The God Equation* (Doubleday, 2021), chronicles the long quest to create a "theory of everything" that would combine Einstein's model of general relativity with quantum theory, and potentially unlock new understandings of space and time.

Kaku caught up with *Discover* to chat about what fascinated him about this quest as a young child, why subatomic particles are like notes on a vibrating string, and what we can learn from science fiction.

MICHIO KAKU. BACKGROUND: NATALI ART COLLECTIONS/SHUTTERSTOCK

Q In your book, you describe an all-encompassing "theory of everything" as the holy grail of physics. Why is a theory like that so important?

MK: When Newton worked out the laws of gravity and mechanics, that set into motion what eventually became the Industrial Revolution, which lifted humanity out of agrarian misery and poverty. When Maxwell and Faraday worked out the laws of electricity and magnetism, that set into motion the Electric Revolution, which gave us electricity, radio, TV, dynamos, and generators. When Heisenberg and Schrödinger worked out the laws of the quantum and the atom, that gave us lasers, transistors, computers and the internet. So, every time physicists explain a force of nature, it alters the destiny of the human race and the world economy.

And now, we are on the verge of a theory of everything, which can unite all the forces of the universe via an equation perhaps no more than an inch long. Eventually, this may once again alter the destiny of humanity. It may also answer the deepest questions about the universe, such as: Can we break the light barrier and reach the stars? What happened before the Big Bang? Are there other universes and dimensions? Is time travel possible? Are wormholes possible?

Q The quest for this theory captivated some of history's most famous scientists. What was it about a theory of everything that first ignited your imagination?

MK: When I was 8 years old, something happened which changed my life. All the newspapers said that a great scientist had just died. But they printed a picture of his desk, with an open book. Over the years, I discovered that this man's name was Albert Einstein, and that this book was the unfinished unified field theory, which could unify all the laws of nature into a single equation. I had to know what was in that book, and why he could not finish it. This became the focus of my life.

> "All the subatomic particles of nature are like musical notes on a tiny vibrating string."

Today, the leading (and only) candidate for this theory of everything is called string theory. I have had the privilege of working on this theory since 1968. My contribution was — along with Professor Keiji Kikkawa — to create string field theory, which can summarize string theory in an equation about 1 inch long. However, it is not the final theory, since now we know that membranes can also exist along with string.

Q How would you describe string theory?

MK: To understand string theory, imagine a rubber band, which represents a tiny, tiny electron. If you stretch the rubber band, it vibrates at a precise frequency. If you twang the band, it vibrates at a different frequency — call it a neutrino. If you twang it again, it becomes a different frequency; call it a quark. In fact, there are an unlimited number of frequencies that the band can vibrate, corresponding to an infinite number of possible subatomic particles.

So all the subatomic particles of nature are like musical notes on a tiny vibrating string. The kernel of this idea was proposed over 2,000 years ago by the great mathematician Pythagoras. He realized that a lyre string can vibrate with an infinite number of musical notes, each one corresponding to a resonance or frequency. He then proposed that the vast diversity of matter that we see around us is nothing but the harmonies found on strings. Only music, he thought, was rich enough to make sense of the vast complexity of the universe.

Q Your book *Physics of the Impossible* explores the plausibility of different sci-fi conceits, like force fields, hyperspace and time travel. Now you're teaching a course about the physics of science fiction. Why are you drawn to these concepts?

MK: When I was 8 years old, on Saturday morning, I used to watch the old *Flash Gordon* series. Ray guns. Cities in the sky. Invisibility rays. Cities under the oceans. I was hooked. Years later, I realized that my two loves, Einstein's unified field theory and science fiction, were related. In order to understand whether science fiction is possible, plausible, or impossible, you need physics. I used to go to sci-fi movies and count the number of laws of physics that are violated.

Q Do you have a personal favorite sci-fi technology or concept?

MK: My favorite science fiction novels are the *Foundation* series by Asimov, because they force you to imagine a galactic civilization 50,000 years into the future, when new laws of physics open up. Things that we consider impossible (like breaking the light barrier) might become possible. All bets are off. — ALEX ORLANDO

This interview has been edited and condensed for clarity.

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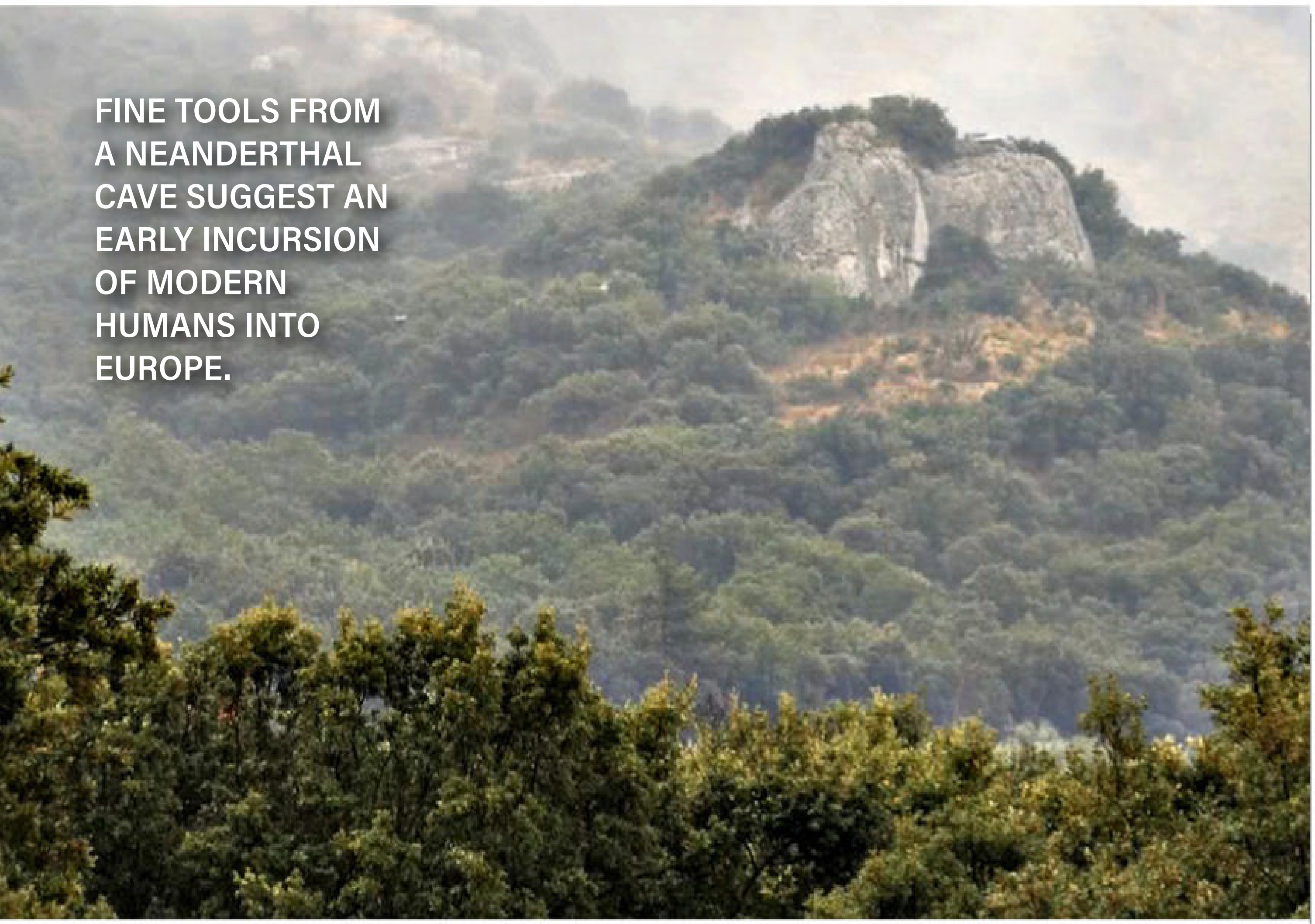


FINE TOOLS FROM A NEANDERTHAL CAVE SUGGEST AN EARLY INCURSION OF MODERN HUMANS INTO EUROPE.

ARCHAEOLOGISTS DUG up hundreds of stone tools (below) from a cave in France.

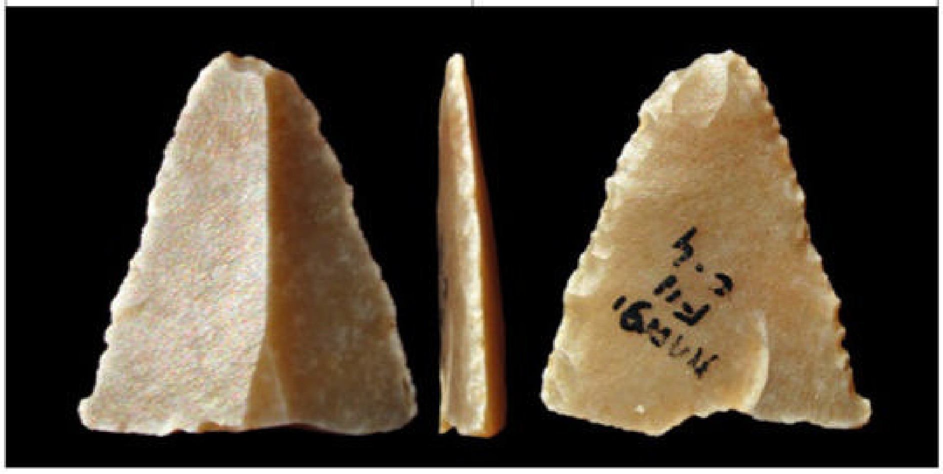
The Neanderthal-Sapiens Timeshare

OVER 700 feet (or about 60 stories) above France's Rhône River stands a cave with more than 40,000 years' worth of Neanderthal debris. Digging through the materials since the 1990s, archaeologists have found traces of campfires, butchered animal bones and well over 50,000 stone tools crafted in the broad, flat fashion typical of Neanderthals.

But after years of excavations, halfway down the 10-foot-deep pits, archaeologists uncovered hundreds of stone artifacts that didn't belong: finely pointed tools that resembled arrow tips. "Something is not normal in this layer," says Laure Metz, an archaeologist at Aix-Marseille University in France. "Something happened."

In a February *Science Advances* paper combining three decades of research, Metz and colleagues concluded that "something" was *sapiens*: Modern humans inhabited the site, known as Mandrin, and filled it with their tools for one or two generations in the midst of millennia of Neanderthal occupation. Occurring 54,000 years ago, this short stint in Europe predates our species' migration to the continent by 10,000 years.

To determine that *sapiens* left these points, the researchers compared the tools to those found at other digs. Based on their shape and subtle scars, the Mandrin points most resembled tools found alongside *Homo sapiens* fossils in present-day Lebanon — suggesting the squatters migrated from the Near East.



Colleagues also examined nine teeth found inside the cave. The only probable *sapiens* specimen, a baby tooth, came from the same layer as the foreign-looking points. Metz says the molar provided proof modern humans entered Mandrin 54,000 years back.

These *sapiens* almost certainly encountered Neanderthals, as both groups roamed the surrounding lands. Metz says "the meeting was not a bad one," at least not initially. The quality material of the modern humans' tools suggests the local Neanderthals showed them where to find the best rock, "like the tourists' guide."

But perhaps that hospitality waned. By dating campfire soot trapped in the cave, researchers showed the modern folks only lasted about 40 years; Neanderthals reclaimed the cave for the next 12,000. —BRIDGET ALEX

LAURE METZ (3)

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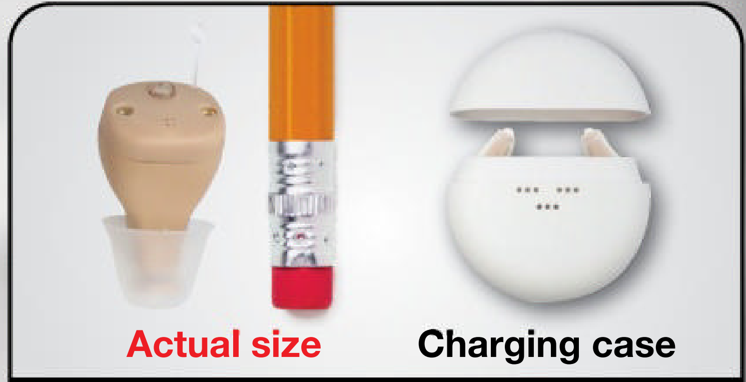

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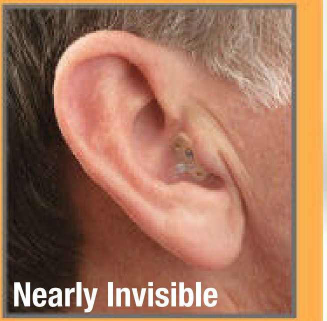

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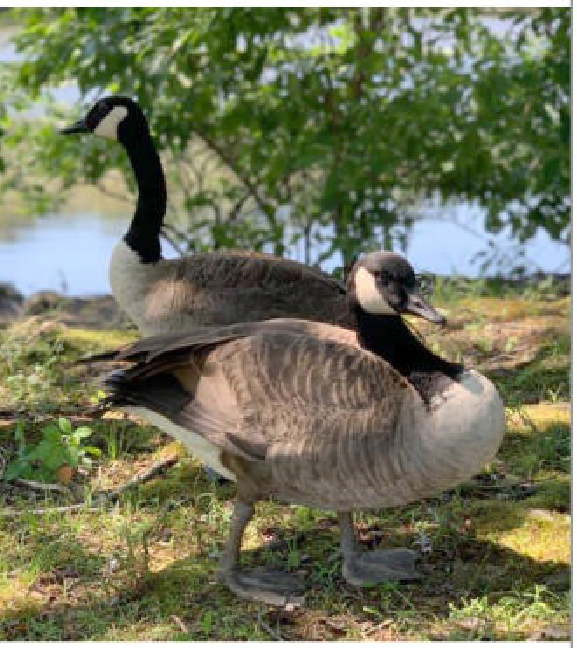
FOWLS IN LOVE

GEESE ARE FAMOUSLY LOYAL AND MATE FOR LIFE. COULD A LIFE-THREATENING INJURY PUT THAT PARTNERSHIP AT RISK?

ARNOLD AND AMELIA live near the Birdsey Cape Wildlife Center in Barnstable, Massachusetts. The employees at the center often notice them walking together near a pond, though they keep their distance and rarely interact with others. It's the typical picture of a young couple in love, right? Except in this case, Arnold and Amelia are wild Canada geese.

It's not an uncommon sight. An estimated 90 percent of all bird species form pair bonds, often leading to the co-parenting of offspring and sometimes lifelong partnerships. On top of this, geese are social animals that travel together, and even enjoy higher social rankings than their fellows after finding "the one," gaining access to better foraging and nesting opportunities.

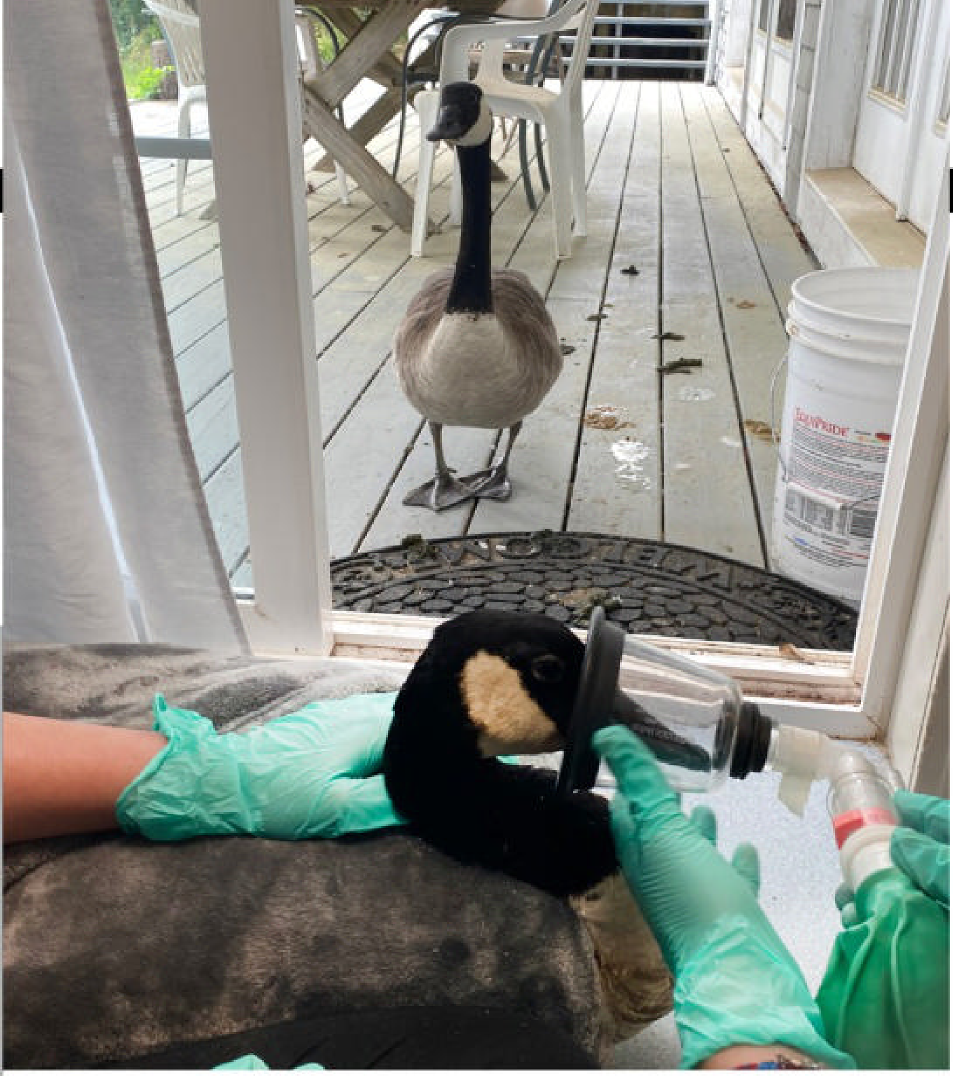


But for Arnold and Amelia, this past summer tested the strength of that partnership. "We noticed that one of the geese [Arnold] was limping pretty significantly," says Zak Mertz, executive director of the Birdsey Cape Wildlife Center. After examining Arnold, he discovered an open fracture. The injury wouldn't heal on its own in the wild and, if left untreated, would likely spell Arnold's eventual demise.

Greg Mertz, a veterinarian and chairman at the New England Wildlife Center and Zak's father, explains that foot fractures are a common injury for Canada geese. "Snapping turtles come up from below and grab the goose by the foot. If it's a baby, the baby will often succumb, but an adult can probably struggle enough to get away," he says.

While observing the surgery to repair Arnold's foot, Zak heard a tapping sound on the clinic's sliding glass door. When he went to investigate the source of the sound, he found none other than Amelia, taking advantage of a clear view of the table where Arnold was anesthetized.

After Arnold awoke from surgery, the staff allowed Amelia into the room. She immediately began preening him when she saw him, using her beak to clean his feathers. The activity can also be a form of communication between mates.



AMELIA PEERS IN from outside as her mate, Arnold, is prepped for surgery to repair his fractured foot.

NEW ENGLAND WILDLIFE CENTERS (2)

FOR THE NEXT 14 days, Arnold recuperated from his surgery. During this time, Amelia was at the wildlife center every day, sharing his meals and spending time with him. Sometimes she waddled down to the pond, but she always returned. And when Arnold was well enough, he was allowed outside too.

After Arnold was released, the staff continued to spot the pair together for about two weeks. Then a flock of geese landed in the pond and since that time, no one has seen Arnold or Amelia. "My guess would be that they took up with the flock and moved on," says Zak.

Greg explains that because the couple didn't have any babies, they were most likely young. "If a Canada goose goes for some time without having contact or repaid interest by the other mate, then they will separate," he says. "It's a little dramatic, but about 10 percent of geese end up getting divorced." A recent study found that the most common reason geese pairs split is a low number of hatchlings.

But surely Amelia visiting Arnold while he was injured cemented their bond — does this mean they were in love? "Part of the reason we take such a vested interest in animals is because we draw similarities between their behaviors and our behaviors," says Zak. "They protect each other, they reproduce together, they depend on each other, but whether there's an intrinsic sense of love, I don't know."

Greg adds that biological influences can keep a goose couple together, something that humans experience as well. "There has to be some internal motivating force that allows that animal to behave in a particular way, and we call it love — that internal driving force."

—CHERYL MAGUIRE

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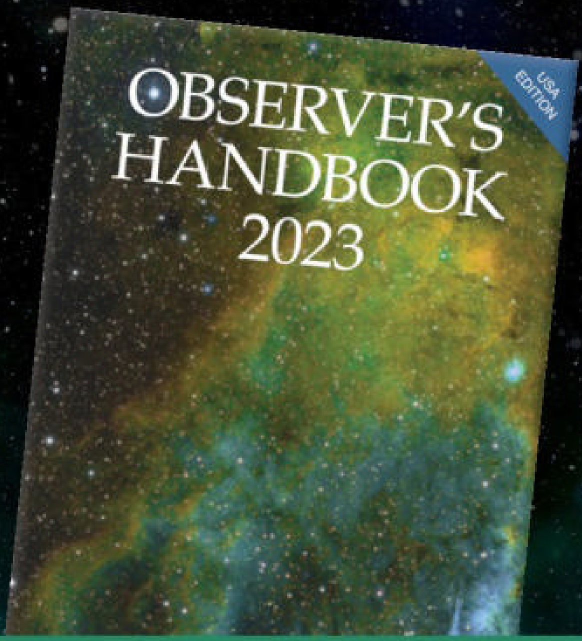

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Scientists Are Vacuuming Animal DNA Out of the Air

AN IMAGINATIVE NEW TECHNOLOGY COULD REVOLUTIONIZE THE STUDY OF BIODIVERSITY AND HELP SAVE ENDANGERED SPECIES.

KRISTINE BOHMANN has a habit of using unconventional means to gather data. She once offered herself as bait to leeches in Madagascar, hoping to find in their guts the genetic traces of the animals they had been feeding on. But Bohmann, an ecologist at the University of Copenhagen in Denmark, has recently developed a less medieval method of finding animals: vacuuming their DNA out of the sky.

BOHMANN and co. used specialized devices (above) to collect airborne animal DNA at the Copenhagen Zoo.

In late 2021, Bohmann and her colleagues detected dozens of captive animal species at the Copenhagen Zoo, as well as nearby free-roaming creatures like squirrels and cats — even when those animals were outside the zoo's walls. Essentially, the technique involves vacuuming or blowing air through a filter to extract genetic material for sequencing and analysis.

Unbeknownst to all involved, a separate group of researchers from Queen Mary University of London built their own DNA vacuum back in 2020. After discovering the coincidence of similar research efforts, the teams opted to publish their findings together. The two papers, published in February 2022 in *Current Biology*, serve as proof of concept for a tool that could revolutionize biodiversity monitoring and improve ecological decision-making. In practice, DNA vacuuming could more effectively map the habitats of threatened and endangered species. "We've demonstrated this can work extremely well," says Elizabeth Clare, a biologist at York University in Toronto, who led the British study. "What we now need to figure out is under what conditions does it work."

THE AIR AROUND us is 78 percent nitrogen, 21 percent oxygen and, surprisingly, some teeny fraction of a percent DNA. Living creatures are constantly "shedding" bits of their genomes into the environment, through saliva, skin, feces, fur, feathers and more. These are are excellent hints for mapping out an ecosystem's inhabitants, but the microscopic particles wafting from them could prove even more useful.

Over the past couple of decades, an entire genre of research has sprung up around environmental DNA (eDNA). Whereas human observers and camera traps require a physical animal in the right place at the right time, eDNA "is more like a footprint," Clare says. "It gets left behind, and it lasts much longer."

Genetic material has been extracted from rain, soil and even honey. Bodies of water have been especially handy for surveying both aquatic and terrestrial populations. But the burgeoning field has overlooked the stuff we breathe.

Air, as a medium for DNA research, is at once appealing and daunting. It's everywhere, so easy to sample, yet still enigmatic and irregular. At the Hamerton Zoo Park in Cambridgeshire, where she conducted her tests, Clare regularly picked up DNA from enclosures hundreds of yards away. One prolific lemur appeared almost everywhere. But another species of lemur never showed up once, even when she vacuumed right beside it.

Still, judging by her and Bohmann's expectations, the experiments were wildly successful. At the start, the investigators were all but certain of complete failure. (Both received their funding from high-risk grants for implausible technologies.) Instead, they found a whole menagerie — 49 species in Denmark, and 25 in England, detected in both sealed enclosures and open air. They even detected evidence of fish that were only used as feed for other animals. "It was just mind blowing," Bohmann says.

The two groups used substantially different methods, which suggests that collecting airborne DNA is much easier than anyone predicted. "This is what the next experiment should be: Can we actually detect animals in the wild?" Clare says. "The answer is: We already did." — CODY COTTIER

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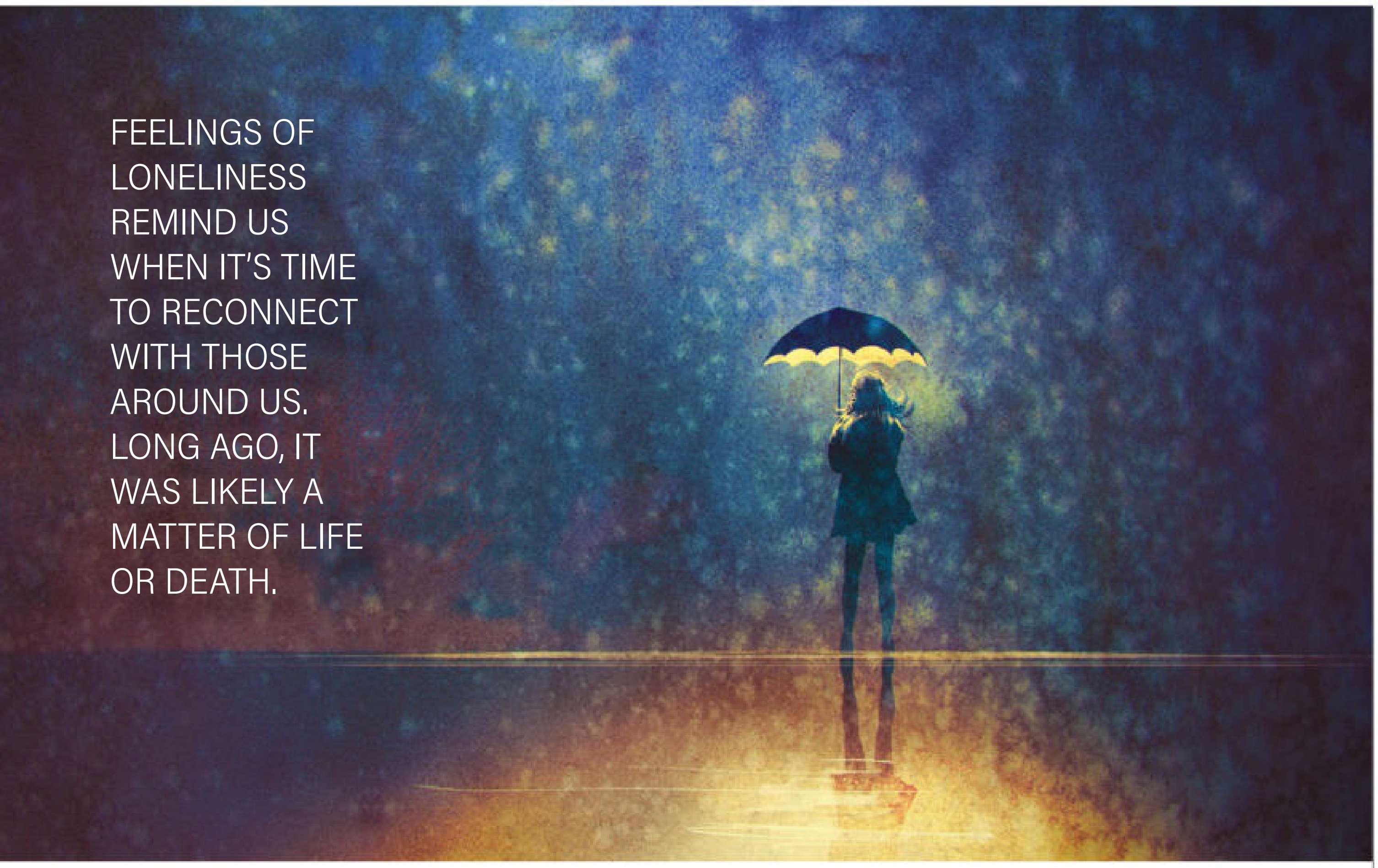

FEELINGS OF LONELINESS REMIND US WHEN IT'S TIME TO RECONNECT WITH THOSE AROUND US. LONG AGO, IT WAS LIKELY A MATTER OF LIFE OR DEATH.

Humans Evolved to Be Lonely

A HEAVY feeling on the chest. A throat that's leaden. An unrelenting and overwhelming feeling of isolation. Loneliness hurts — and, over time, it can put the body into a vicious inflammatory state that increases our risk of everything from heart attack and stroke to diabetes and cancer. So, evolutionarily speaking, why do we experience it?

Stephanie Cacioppo, a neuroscientist at the University of Chicago Pritzker School of Medicine, says that countless studies have helped researchers formulate a holistic purpose for loneliness. "Our social structures evolved hand in hand with neural, hormonal and genetic mechanisms to support these social structures" — like couples, tribes and communities — "that help us survive and reproduce," says Cacioppo.

While loneliness may be painful to experience today, for our prehistoric ancestors that pain would've been a far better alternative to being caught alone with a saber-toothed predator on the prowl.

BEING SOCIAL had its downsides even back then — competition for food, for example, or contribution to the spread of pathogens. But scientists think we evolved to feel loneliness because it was more important to work with one another to accomplish tasks and protect everyone. "The pain of loneliness prompted us to renew the social structure so we could survive and promote key features like trust, cooperation and collective action," explains Cacioppo.

She says that, for years, researchers thought of loneliness as a "disease with no redeeming features." But now, they're realizing that it's more of a biological hunger signal that reminds us when it's time to reconnect with those around us to promote our short-term survival. If the outcomes of loneliness were entirely negative, it would no longer be a part of our DNA. "Hunger and thirst protect our physical body while loneliness protects our social body," says Cacioppo.

Interestingly, while loneliness sends a signal to the brain that it's time for connection, at the same time it's also looking for danger. This "paradoxical signal," according to Cacioppo, reminds us to be wary of whether the people we are connecting with are foes or friends. She calls this need to be vigilant even as we're socializing a "self-protection mechanism." That means in situations where you feel lonely even when surrounded by others, you're subconsciously thinking that this crowd might not be a good evolutionary fit for your survival.

THAT SAID, loneliness impacts us all differently. While it is universal and we're all vulnerable to it, says Cacioppo, some of us may find certain situations lonely though others don't. She adds that there's also a genetic component: Some of us are born to feel lonelier than others.

Other factors play a role, too. According to Nathan Spreng, director of the Laboratory of Brain and Cognition at the Montreal Neurological Institute, the way we were treated as children — including how much attention we were given — can also inform how lonely we feel as adults.

Spreng says that over time, loneliness is a self-fulfilling prophecy. Lonely people spend most of their time deep within their own imaginations; they may conceptualize social encounters so much, in fact, that this part of their brain is in overdrive. "People who are really lonely may be desperate to form connections," he says. "But they aren't as present, so they might miss the social cues necessary to form deeper connections." — SARA NOVAK

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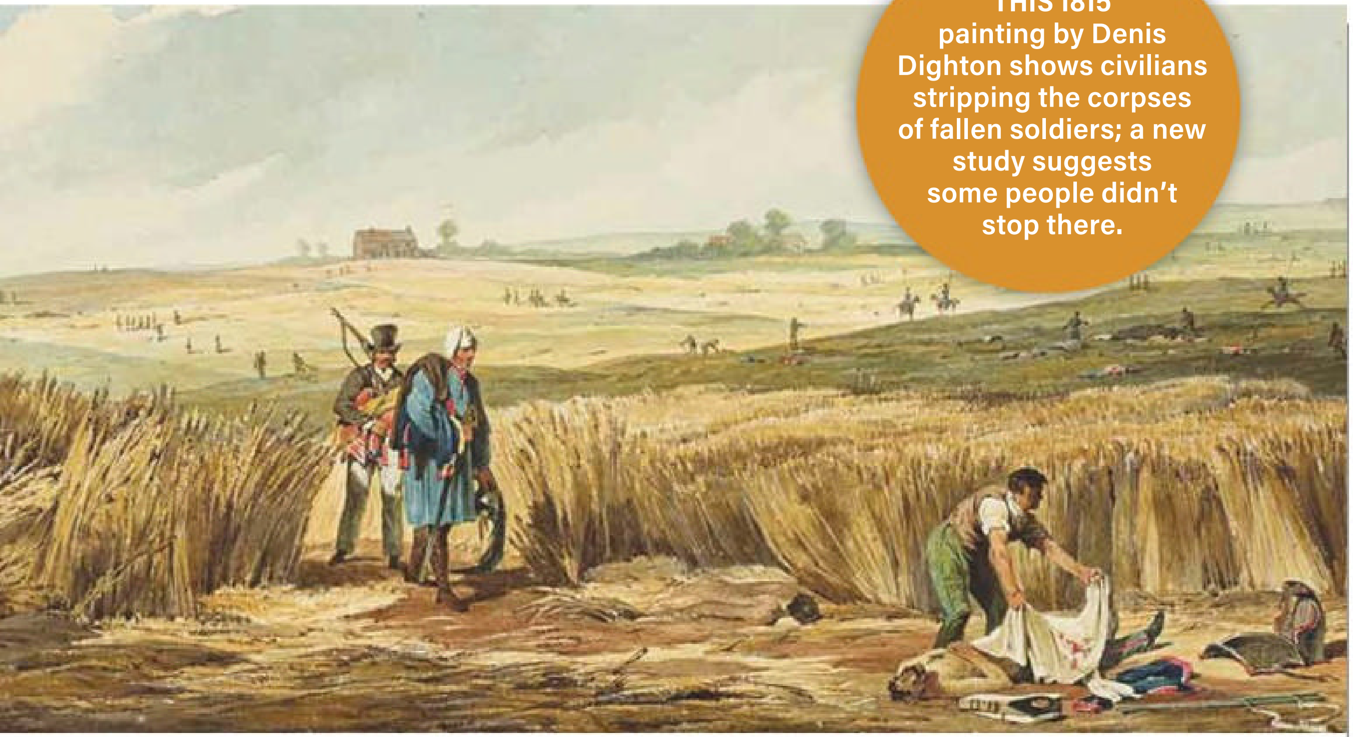

THIS 1815 painting by Denis Dighton shows civilians stripping the corpses of fallen soldiers; a new study suggests some people didn't stop there.

DENIS DIGHTON/WIKIMEDIA COMMONS

Mapping the Bodies of Waterloo

ALMOST NO HUMAN REMAINS HAVE BEEN FOUND FROM ONE OF THE DEADLIEST BATTLES IN HISTORY. NEW RESEARCH FOLLOWS WHERE THEY MIGHT HAVE ENDED UP.

ON JUNE 18, 1815, the Duke of Wellington defeated Napoleon Bonaparte's army at Waterloo (then in the Netherlands, today in Belgium), marking the end of the First French Empire. For 24 grueling hours, the armies clashed in the mud with muskets, lances and swords, leaving 50,000 soldiers dead.

The battle was one of the deadliest of the century — and yet, almost no human remains have been found in the battlefield area. But now, for the first time, analysis of historical written accounts and artwork has been used to plot a map that may shed some light on the burials.

There are a variety of reasons the Waterloo dead are missing, writes Tony Pollard, director of the Centre for Battlefield Archaeology at the University of Glasgow, in a study published in the *Journal of Conflict Archaeology* in June. Many of the remains were burned as a means of disposal. Other accounts depict smaller graves so hastily dug that arms and legs stuck out, which may have been disturbed, separated, and turned into the ground by ploughs when the land around the battlefield was quickly reclaimed for farming after the conflict ended.

And, Pollard says, there's a good chance many of the bones were stolen: Newspaper clippings from the era to demonstrate that people commonly looted human bones and sold them to make fertilizer. For example, one clipping from *The London Observer* in 1822 estimates that "more than a million bushels of human and inhuman bones were imported from the continent of Europe into the port of Hull."

"European battlefields may have provided a convenient source of bone that could be ground down into bone-meal, an effective form of fertilizer," Pollard said in a press release. Scavenging for trophies and souvenirs as well as clothing and other usable supplies immediately after the battle is well documented. And locals who watched or helped with the burials could have easily guided graverobbers to the gravesites. Considering the importance of bone meal in agriculture at the time, Pollard said, emptying the mass graves at Waterloo to procure human bones isn't just a possibility, but rather the most likely conclusion.

> The battle was one of the deadliest of the century — and yet, almost no human remains have been found.

And yet, it's not a certainty. Pollard's work lays out a counterargument that admits that the absence of contemporary accounts of the removal and sale of bones from Waterloo is puzzling — especially considering the written accounts and artwork of the time period give detailed information about the stripping of bodies, battlefield scavenging, burning of corpses, and burials in mass and single graves.

Those accounts will guide the next steps for Waterloo Uncovered, the archaeological project Pollard directs. His study analyzed and collated travel guides, personal memoirs, and letters from visitors to the site, as well as paintings and illustrations of the battle aftermath. The details gleaned from those sources were used to create a map plotting the most likely location of single and mass graves and pyres, in the first attempt to use historical accounts to locate Waterloo burials.

Waterloo Uncovered will use that map to inform its locations for upcoming archaeological work, looking for both extant remains and emptied gravesites that may have supplied Europe with bone-meal. "If human remains have been removed on the scale proposed," Pollard said, "then there should be, at least in some cases, archaeological evidence of the pits from which they were taken, however truncated and poorly defined these might be." —JASON P. DINH AND ELISA R. NECKAR

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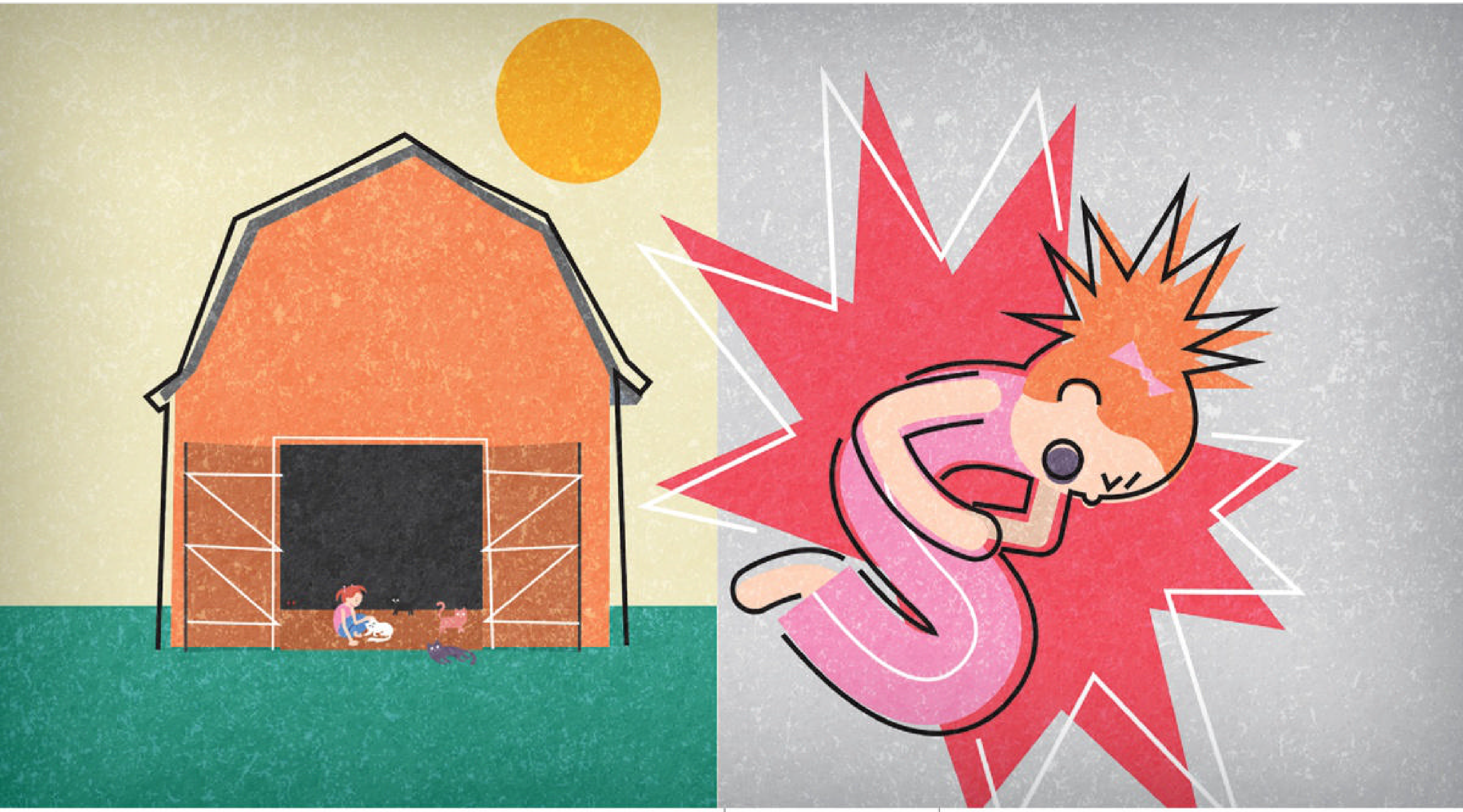

KELLIE JAEGER/DISCOVER

Doubled Over

A MYSTERIOUS PAIN IN HER GUT HAD THIS 4-YEAR-OLD SCREAMING IN AGONY FOR HOURS.

The tiny girl's wails echoed down the hallway of the pediatric emergency department. Only 4 years old, Emma was in relentless pain, crying and cradling her tender belly. Her doctors and nurses had tried a variety of pain medications, heating pads and distracting toys, yet nothing seemed to calm her. They didn't see any obvious cause of her severe distress. Her parents were in tears.

Just a few hours before, Emma had been her joyful, happy self, playing in the family's barn with their cat's litter of new kittens. She giggled in the hayloft as the kittens jumped around her. Suddenly, her parents heard her scream from the shed nearby. They found her doubled over, clutching her stomach and unable to walk.

"What happened?" her father asked, wondering if she had fallen or gotten scratched by a mischievous kitten.

"I don't know," she replied, "I just started hurting a lot!"

Her mother gave her a bath and some Tylenol. But Emma's screams continued, prompting her parents to bring her to our hospital.

Emma cried the whole way to the CT scanner, despite many strong doses of IV pain medication.

"She looks like an appendicitis case," the triage nurse told us shortly after Emma was settled in a room. I peeked in the door to find her shuffling toward the bed, arms clutching her lower abdomen, sweating and panting; her face was contorted in discomfort.

As I examined her, Emma nearly jumped off the bed when I touched the right lower part of her abdomen, tensing her belly in response. She promptly vomited and continued to cry in pain.

The location and severity of her pain prompted concern for either appendicitis or a problem with her ovary, such as a twisting of the nearby blood vessels — these were true emergencies. We rushed Emma off for an ultrasound to figure out what was troubling her belly so much.

I LOOKED AT the ultrasound with shock: Emma's appendix was entirely normal. Her ovaries and their blood

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BLACK WIDOWS ARE HEADING NORTH

As climate change increasingly shifts the habitats of different species, the distribution of the northern black widow (*Latrodectus variolus*) is expanding into what used to be prohibitively cold habitats. A team of Canadian researchers used citizen-science data to determine that the northernmost range of the species has increased by more than 30 miles between 1960 and 2016, according to an article published in *PLOS One* in 2018. Today, the arachnids can be found in parts of eastern Ontario and southern Québec.

flow were entirely normal, as well. We had to look deeper — this time, with a CT scan and blood tests. Emma cried the whole way to the scanner, despite many doses of strong IV pain medication.

As we took more pictures, I probed her parents about any injury, new exposure, signs of illness or even any history of stomach problems. They couldn't recall anything out of the ordinary, just her abrupt pain while playing in the barn.

Her CT images didn't help, either. They showed no obvious cause for Emma's pain; no abscess, no mass, no blockage in her intestine, no sign of kidney stones. As far as the scans showed, there was simply nothing wrong. Her blood tests revealed nothing, as well. We were stumped.

I decided to call a pediatric emergency medicine colleague of mine. She had a curious question for me: "Did you look at her skin?" she asked, "Particularly for any bites or goosebumps?"

I realized I never had looked closely at her skin. Sure enough, when I returned to Emma's bedside, there it was: a patch of goosebumps on her abdomen surrounding faint bite marks, the skin around them now turning a shade of purple. We hadn't noticed the spot before; distracted by a deeper internal cause, we forgot to look on the surface.

"Yup, there are goosebumps surrounding two tiny punctures," I told my colleague over the phone.

"It's a black widow spider bite," she replied, "That's why she's in such severe pain with normal findings otherwise. And why she's sweating and vomiting. Give her antivenom."

WHEN BLACK WIDOW spiders bite humans, they can cause an illness known as lactrodectism, named for the arachnid's genus, *Lactrodectus*. With their bite, they inject a potent toxin that acts on the body's nervous system, causing it to release large amounts of neurotransmitters. This leads to searing pain, cramping muscles, sweaty skin and abnormally high heart rate and blood pressure.

Often, victims are unaware they were bitten, making lactrodectism a tricky diagnosis. Physicians can attribute these symptoms to more common ailments — like the tense, painful abdomen of appendicitis or a bowel obstruction, or the sweating and elevated heart rate caused by a medication overdose.

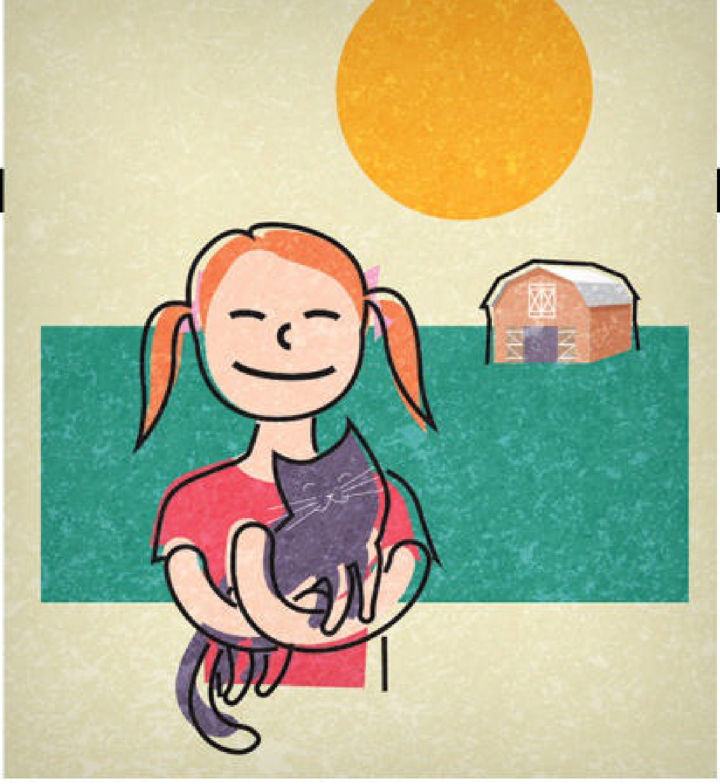
But a careful look for the classic pair of puncture wounds, and the surrounding goosebumps, can offer a helpful clue: As hours pass, the bite begins to take on a purplish hue, the skin blistering and ulcerating. At this point, the lesion is hard to miss, often clinching the diagnosis.

Though lactrodectism is extremely uncomfortable, it occurs rarely — and is usually not fatal. The black widow spider gets its ominous name from its habit of sometimes killing its partner after mating, not because it's especially adept at killing humans. Only the females inject venom, and generally do so only when they are disturbed.

Despite the fear they tend to induce, black widow spider bites are unusual. About 2,600 bites are reported to U.S. poison control centers each year, and deaths are extremely rare. More often,

Often, victims are unaware they were bit, making lactrodectism a tricky diagnosis.

KELLIE JAEGER/DISCOVER (3)



Without a clear, witnessed bite from a spider, it's best to seek medical care before worrying too much about black widows.

what someone is concerned may be a black widow bite ends up being caused by other spiders or other insects entirely — or isn't even a bite at all, but rather local allergic reaction or skin infection. Without a clear, witnessed bite from a spider, it's best to seek medical care before worrying too much about black widows.

Black widow spiders tend to live in dry, dark, secluded spots such as barns, sheds, closets and basements; in the U.S., they're found primarily in the South and West. Emma had been so focused on her new kittens she didn't see the spider, its shiny black body marked by a red hourglass, crawl from a hay bale to the underside of her shirt and bite her right in the belly.

We now had a solution to Emma's terrible discomfort: black widow spider antivenom. Twenty minutes after it was infused into her vein, Emma's pain was gone. Her heart rate and blood pressure normalized. Her muscles relaxed. Then, relief washed over her face, and she stopped crying for the first time since I had met her. "It's like magic!" her parents exclaimed, their tears of distress now replaced by those of joy.

Emma stayed for a few more hours to finish her infusion and ensure her symptoms resolved. She ate a snack, took a nap and watched a few episodes of her favorite cartoon, no further pain medications required. She asked to go home, eager to return to her new kittens. Her parents thanked us as they left, assuring us they would rid their barn of any spiders when they got home. **D**

Julia Michie Bruckner *is a pediatrician at Children's Hospital Colorado. The cases described in Vital Signs are real, but names and certain details have been changed.*

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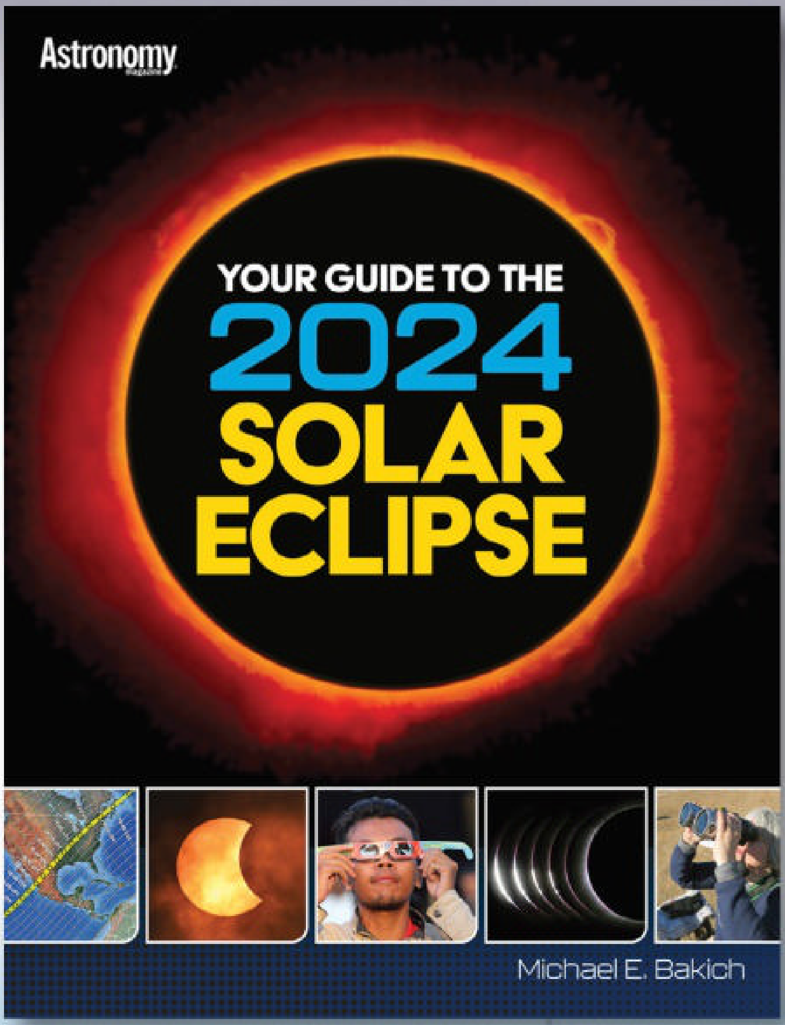

Get all the information you'll need to be ready for the 2024 total solar eclipse! Expected to be the most viewed sky event in history, the April 8, 2024 eclipse is covered extensively in this must-have reference guide written by former *Astronomy* magazine editor and eclipse expert Michael E. Bakich.

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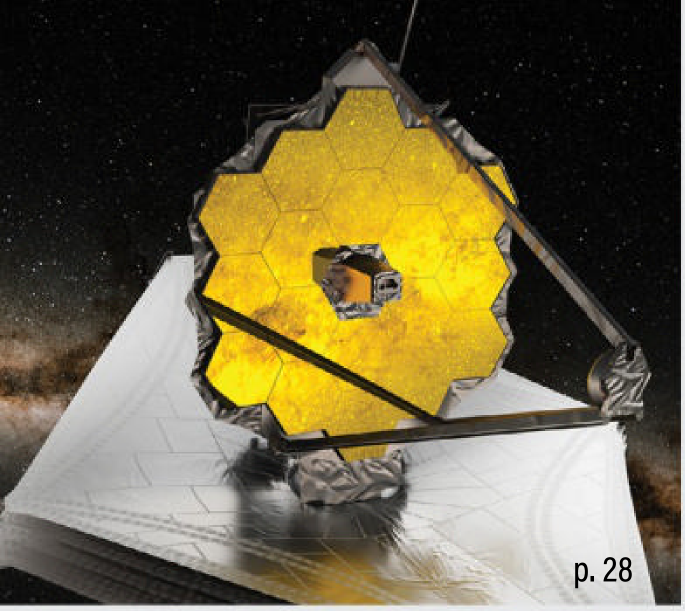
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SPECIAL SECTION

THE STATE OF SCIENCE 2023

Science really is the show that never ends, and in 2022, that show brought a renewed sense of awe and wonder to the world stage. Astounding breakthroughs in cancer research. A controversial new theory about everyone's favorite dinosaur. The discovery of an explorer's long-lost vessel. A stunning new way to view the universe with a clarity we've never seen before. All of these events and many more advanced science in 2022 and will reshape our understanding of the world in the years to come. But now, let's draw back the curtain on *Discover*'s picks for the top science stories of the year. Enjoy the show!

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FROM LEFT: CLAUDIOCARIDI/DREAMSTIME; TONGA GEOLOGICAL SERVICES/WIKIMEDIA COMMONS; PUWADOL JATURAWUTTHICHAI/SHUTTERSTOCK

A FRESH EYE ON THE BEGINNING OF TIME

Infrared observations by the James Webb Space Telescope already reveal a treasure trove of secrets about the cosmos.

THE WHITE HOUSE
WASHINGTON
NASA
JAMES WEBB
SPACE TELESCOPE

AFTER YEARS of preparation (and delay), JWST launched on Dec. 25, 2021. By July, the White House was able to hold a special sneak-peek briefing of the telescope's first image.

CLOCKWISE FROM TOP LEFT: DESIREE STOVE/NASA; NASA/ESA/CSA/STSCI/THE WEBB ERO PRODUCTION TEAM; BILL INGALLS/NASA (2)

IT STANDS as tall as a house, cost $10 billion to build and required 30 years of work by three international space agencies. Its impossibly smooth, segmented mirror is coated with a thin layer of gold, and its instruments hide behind a sunshield as big as a tennis court. In 2022, following a million-mile journey through space, the largest, most expensive and most powerful space telescope ever created finally opened its eyes to the cosmos.

And oh, what a view!

NASA released the first deep-field image from the James Webb Space Telescope (JWST) in July. It revealed a dazzling collection of thousands of galaxies and stars, many of which have hidden beyond the telescopic sight of astronomers until now. That's because JWST sees deeper into space — and further back in time — than any previous observatory on the ground or in space.

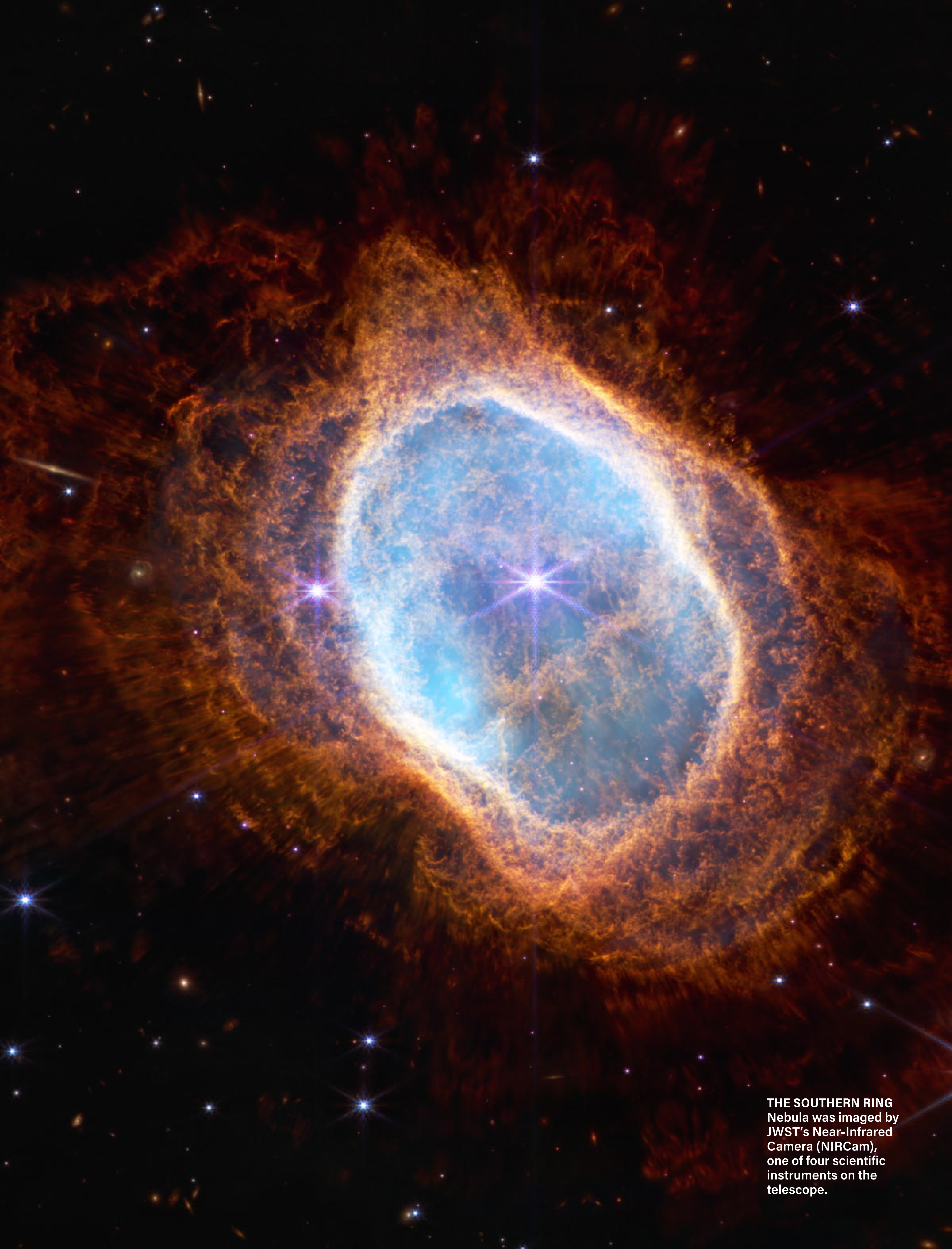
The cosmic wonders in the first image include ancient galaxies and clouds of star-forming dust. The visible objects span almost the entire the lifetime of the universe, with the farthest away appearing as they did more than 13 billion years ago, not long (a mere 700 million years) after the Big Bang. The image represents a swath of space only as big as a grain of sand, held at arm's length. It suggests that no matter which way you look, or at how small a spot, JWST will unveil the cosmos.

Other dazzling observations quickly followed. One image showed the Cartwheel Galaxy, a space oddity in the Sculptor constellation, 500 million light-years away. (See "Year in Photos," page 72.) The telescope also detected evidence of water in the form of haze and clouds in the atmosphere of WASP-96b, an enormous, puffy exoplanet that's larger, but less massive, than Jupiter and orbits a star more than 1,100 light-years away. Even in our own cosmic neighborhood, JWST has imaged Jupiter and Neptune, revealing the planets' rings and parade of moons in astonishing detail.

OTHER FINDINGS from the telescope challenge existing ideas about the earliest galaxies, such as the theory that stars, galaxies and black holes grew slowly after the birth of the universe. Data released last summer suggest that cosmic gas clouds coalesced into these light-emitting objects much sooner after the Big Bang than previously thought. "The first galaxies we see are already filled up with chemical elements," says astrophysicist and Nobel laureate John Mather, JWST's senior project scientist. "It's not just hydrogen and helium."

Mather has been involved in the project almost from the beginning and says the successful observations of JWST represent the very latest advances in the field of precision cosmology. "There's current excitement about the really early universe," he says. "Everything that happened in those first few hundreds of millions of years will be a surprise."

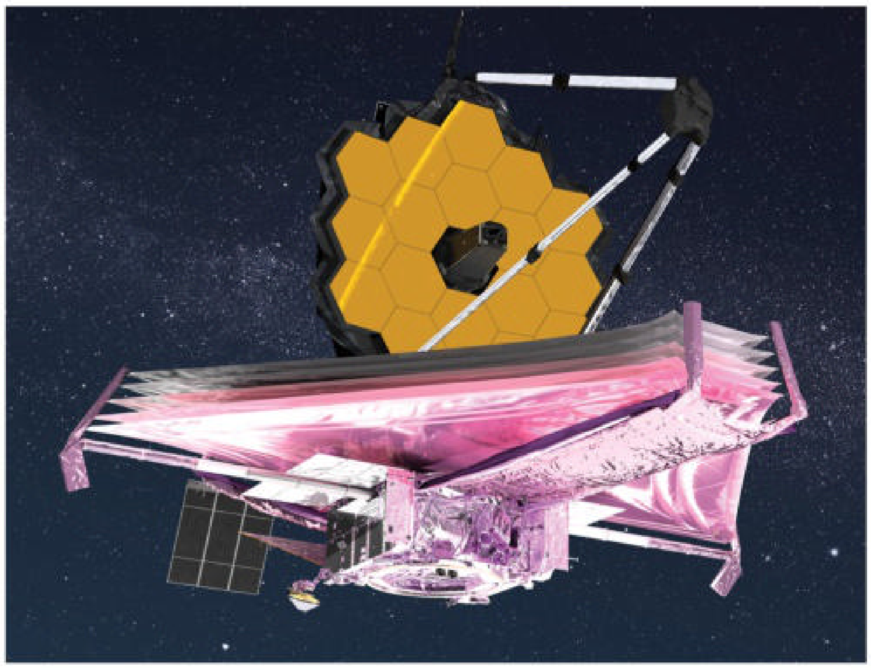
PLANNING FOR a large infrared telescope began in earnest in 1989 at the Space Telescope Science Institute (STScI) in Baltimore, even before the Hubble Space Telescope had launched. In 1995, Mather joined the team, and by 2002, the group had envisioned a



THE SOUTHERN RING Nebula was imaged by JWST's Near-Infrared Camera (NIRCam), one of four scientific instruments on the telescope.

mirror 21 feet in diameter (Hubble's was 8 feet), made up of 18 identical hexagonal pieces arranged in a honeycomb grid. It would have to be shaded from light and heat coming from the sun and Earth, and both mirror and sunshade would need to be precisely folded into a compact launch vehicle — and then unfolded once it reached its home in space.

"We could visually imagine the path [to completing the telescope], but we still had to invent 10 new technologies to be able to do it," Mather says. Finding a sunshade material that could keep the cool side cool — and still unfold into the perfect geometric shape — proved to be an unexpectedly high hurdle, he notes.



AFTER LAUNCH, JWST cleared new hurdles, including the unfolding of its segments and a journey of nearly a million miles.

The original budget was $1 billion, and the telescope was scheduled to launch in 2010. But the cost ballooned, the timeline lagged and repeated bumps in the road threatened the project. In 2011, Congress proposed killing it altogether. During a vibration test in 2018, screws and washers came loose, and fasteners had to be repaired.

Even the telescope's name caused dismay when protesters objected to christening the project in honor of a former NASA administrator whom some historians have linked to homophobic discrimination of federal employees in the mid-20th century. (NASA declined to change the name.)

Eventually, after numerous challenges and decades of testing, JWST enjoyed a smooth liftoff, journey and unfolding. Although a micrometeoroid dinged one of the mirrors, the damage isn't expected to significantly diminish observing ability.

THE TELESCOPE uses four instruments, all custom designed to capture light waves as they travel through

APOLLO 12'S Alan Bean holds a sample container filled with lunar soil, one of several taken back to Earth during the Apollo program.

FIRST PLANTS GROWN IN LUNAR SOIL

THE SPROUTS ARE GOOD NEWS FOR FUTURE LONG-TERM, OFF-WORLD MISSIONS.

» **Last May,** scientists reported that they'd successfully grown plants in extraterrestrial soil for the first time. At the University of Florida's Space Plants Lab in Gainesville, a dozen *Arabidopsis thaliana* plants germinated and grew, each in a few teaspoons of lunar regolith — the dusty material that covers much of the moon.

***ARABIDOPSIS THALIANA*, THE PLANT RESEARCHERS GREW IN LUNAR SOIL, IS RELATED TO MUSTARD GREENS, CAULIFLOWER, BROCCOLI AND OTHER CRUCIFEROUS VEGETABLES, ACCORDING TO NASA.**

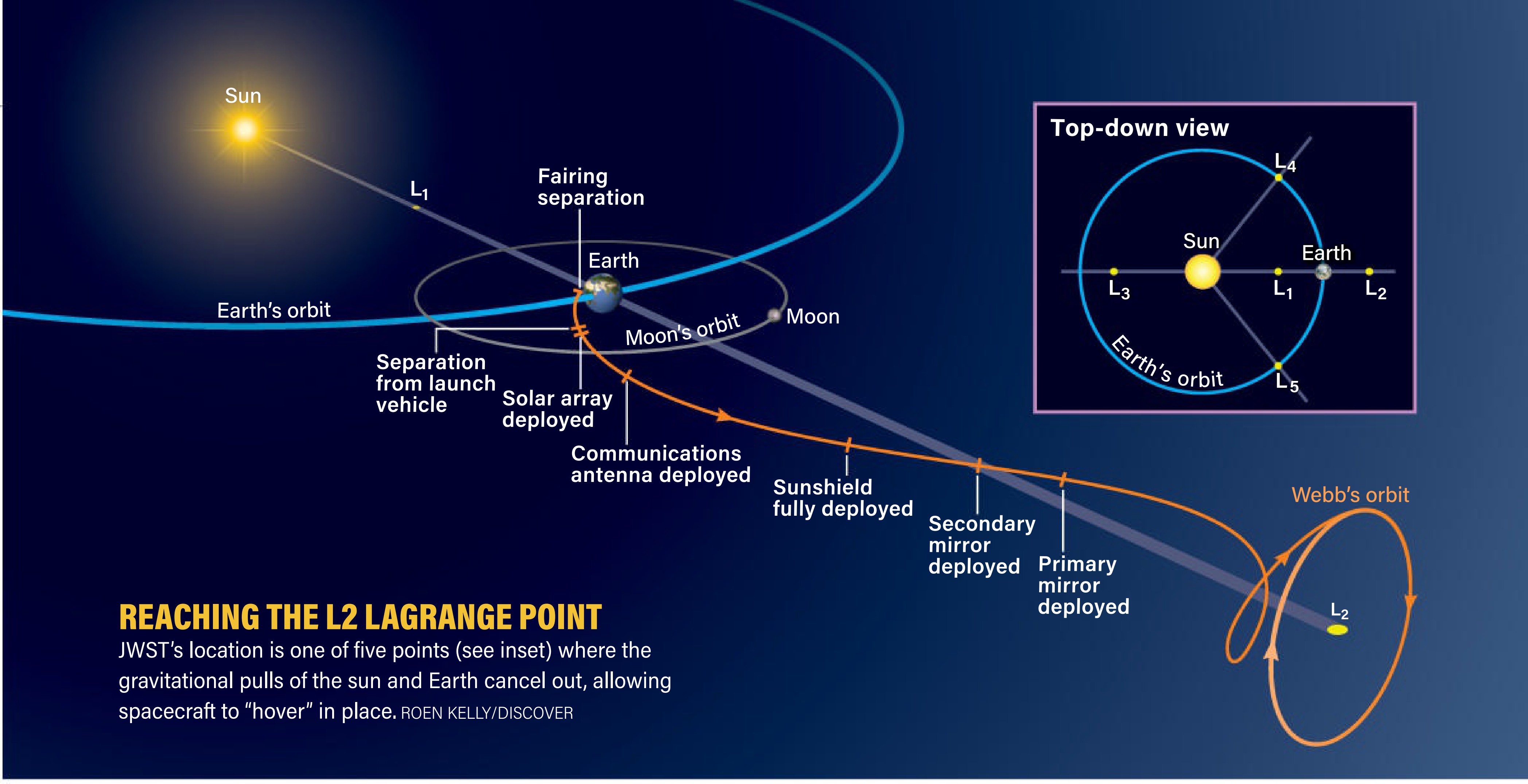
"The first surprise was that they germinated at all," says Rob Ferl, who with fellow horticultural scientist Anna-Lisa Paul, directs the lab. "Lunar regolith is sharp and angular. There was no reason to think that plants would embrace it whatsoever."

The second surprise was how they grew, says Paul. Compared to growth in terrestrial soil, these plants were stunted and stressed. Genetic analyses helped explain why. "Even though they looked well, the plants had to engage different kinds of genes to physiologically adjust to the environment," she says.

Between 1969 and 1972, astronauts collected lunar debris during NASA's Apollo missions. Since then, geologists have analyzed specimens to study the origins and composition of the moon, but biological studies have been lacking.

That's because plants change the soil that they are grown in, says Paul, and so would contaminate the samples. "Once you introduce air and moisture to regolith,

JWST: NASA GSFC/CIL/ADRIANA MANRIQUE GUTIERREZ. ALAN BEAN: NASA. PLANTS: UF/IFAS/TYLER JONES (2)



REACHING THE L2 LAGRANGE POINT
JWST's location is one of five points (see inset) where the gravitational pulls of the sun and Earth cancel out, allowing spacecraft to "hover" in place. ROEN KELLY/DISCOVER

space at the near-infrared part of the spectrum. Because space constantly expands, light waves — some of which have been traveling for billions of years — stretch out over time. That means that light that began in the visible part of the spectrum becomes infrared by the time it reaches our solar system. JWST's gold-plated, super-smooth mirror is designed to collect those wavelengths and reflect them onto a secondary mirror and sensors, converting what would be invisible into stunning, rich visuals.

It's not only the early universe that will be studied by JWST. "The telescope has a full range of science capabilities," says astrophysicist Nancy Levenson, interim director of the STScI. Its data could likely answer questions about early black holes, exoplanet atmospheres and the nature of dark matter. Ultra-precise measurements of the expansion of space could challenge the Standard Model, scientists' best description of the fundamental rules of nature. JWST is poised to reshape much of what we know about the cosmos. "What continues to be so exciting are the questions that we don't even know to ask yet," says Levenson.

Hundreds of researchers have already reserved observing time on JWST, ranging from a few minutes to a few days. Mercedes López-Morales, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics, has already led the publication of papers on exoplanetary atmospheres, based on JWST data.

The flood of papers published since July has also included reports on primitive galaxies, newly found supernovae and ancient black holes, among other objects. Astrophysicist Knicole Colón, who studies exoplanets at the NASA Goddard Space Flight Center in Greenbelt, Maryland, predicts that even the first year will be record-breaking in terms of the findings.

"We have a lot of firsts coming up with this telescope," she says. "It's only the beginning."

— STEPHEN ORNES

THE REAL SURPRISE was that the plants, stunted and stressed from growing in regolith, grew at all.

you start to change the structure of it," says Paul.

The experiment suggests that regolith might be useful for growing food on the moon. It also shows how plants shape alien soil, allowing future missions to the moon, Mars or elsewhere to search for telltale signs that foliage once grew.

"We now have in our laboratories samples from the moon that were invaded by biology," says Ferl.

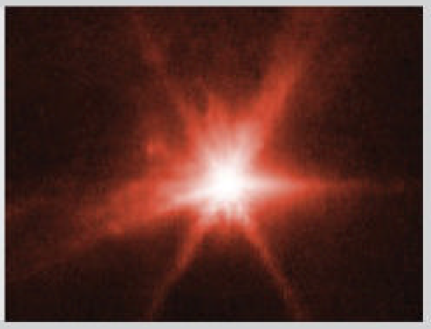
— STEPHEN ORNES

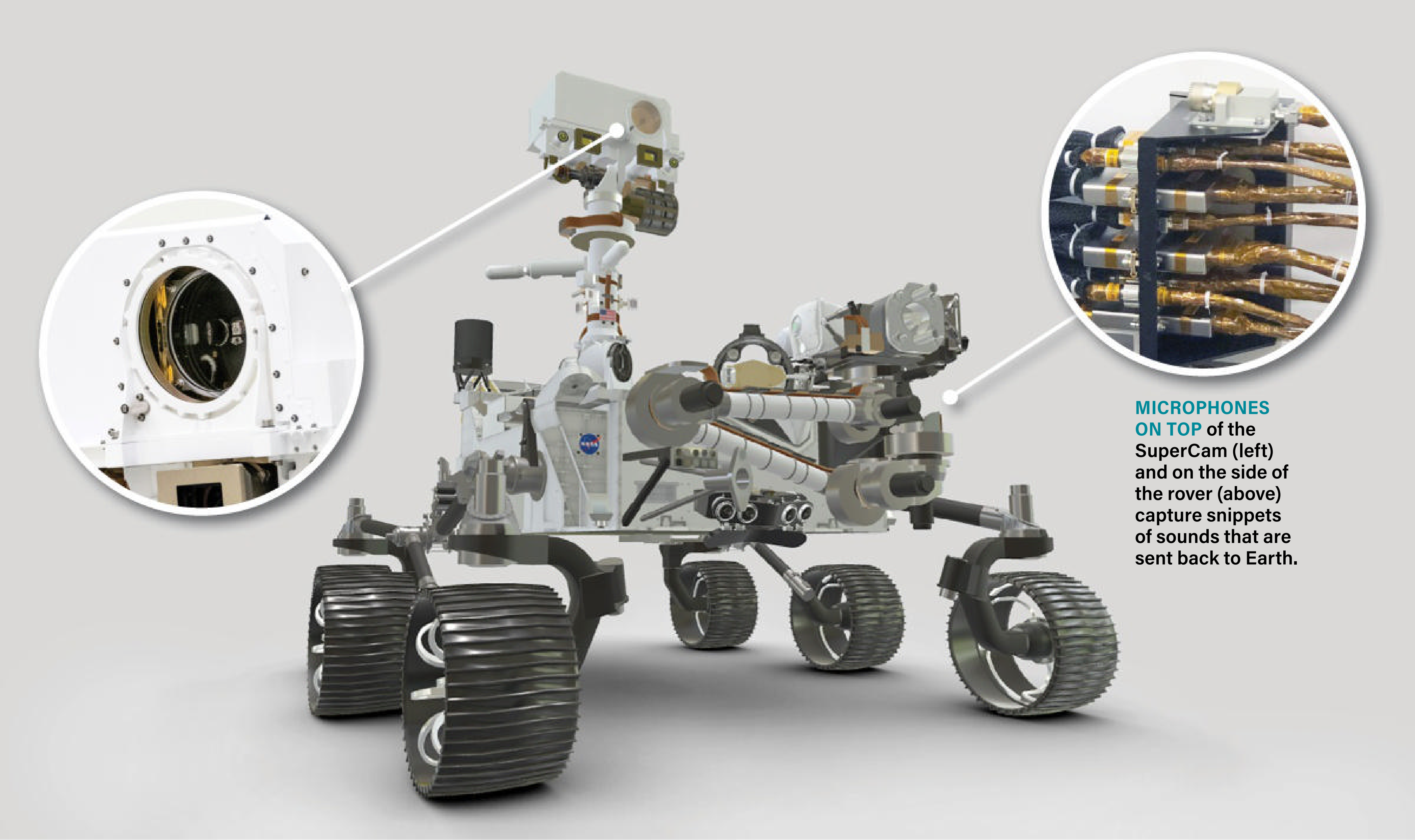
DART: NASA, ESA, CSA, CRISTINA THOMAS (NORTHERN ARIZONA UNIVERSITY), IAN WONG (NASA-GSFC), JOSEPH DEPASQUALE (STSCI)

→ 2022 IN BRIEF

A Bull's-Eye for the DART Mission

On Sept. 26, 2022, the spacecraft from NASA's Double Asteroid Redirection Test (DART) hit the asteroid Dimorphos at 14,000 mph. Both the Hubble Space Telescope and JWST caught the collision and its aftermath (JWST image at right). Successfully changing the asteroid's orbit, the test suggests that such an approach could save Earth from a future impact.





MICROPHONES ON TOP of the SuperCam (left) and on the side of the rover (above) capture snippets of sounds that are sent back to Earth.

MARS ON A HOT MIC

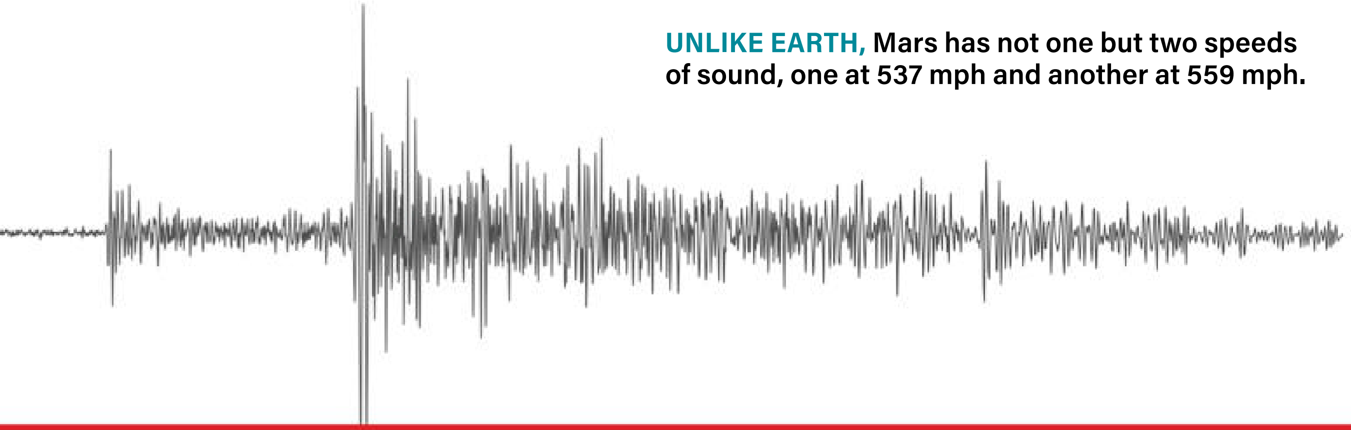
ROVER RECORDINGS REVEAL TWO SPEEDS OF SOUND ON THE RED PLANET.

THE PERSEVERANCE rover has been studying rocks and minerals on Mars since landing there in February 2021. It's also been listening. A microphone mounted on the rover's SuperCam instrument can capture snippets of sound and send them back to Earth. Another microphone, mounted on the side, can monitor sounds coming from the rover itself.

In April 2022, scientists reported that they'd used those soundbites to calculate the speed of sound on Mars. It was part of the first-ever analysis of the acoustic soundscape on Mars, and it didn't turn out exactly as predicted.

"The main surprise was the fact that there are two speeds of sound on Mars," says Baptiste Chide, a planetary scientist at Los Alamos National Laboratory in New Mexico. Chide's job includes listening to the sounds sent back from the Red Planet.

The speed of sound depends on a variety of factors, including the composition and temperature of the medium it travels through. Near Earth's surface, sound travels at about 761 mph. It's slower on Mars — and the speed varies by frequency. Chide's group calculated that higher-pitched waves, above a frequency of about 240 Hertz, move at about 559 mph. Lower-pitched ones, below 240 Hz, are a little slower, at about 537 mph. (Male voices typically fall between 85 and 150 Hz, and female voices between 160 and 270 Hz.)



UNLIKE EARTH, Mars has not one but two speeds of sound, one at 537 mph and another at 559 mph.

The slower speed and differing rates are due to the composition and pressure of the martian atmosphere — it's less than 1 percent as dense as Earth's, and sound travels slower through thinner media. It's also mostly made up of carbon dioxide, and the divide between high-frequency and low-frequency sounds is a unique characteristic of a low-pressure carbon dioxide environment, says Chide.

THE RESEARCHERS also reported that sound on Mars rapidly attenuates — which means it dies out quickly — with higher-pitched sounds dying out

FROM TOP NASA/JPL-CALTECH (3);
NASA/ESA, J. BELL (CORNELL U.) AND M. WOLFF (SSI);
NASA/JPL-CALTECH

SOUND RECORDINGS CAN ENRICH STUDIES OF OTHER EXTRATERRESTRIAL EVENTS AND HELP US TO BETTER UNDERSTAND ALIEN WORLDS.

the fastest. So, if music were playing on a stage in front of you on Mars, it would sound as if it were coming from a greater distance than it would on Earth. The sound would also be garbled because high- and low-frequency sounds would arrive at different times.

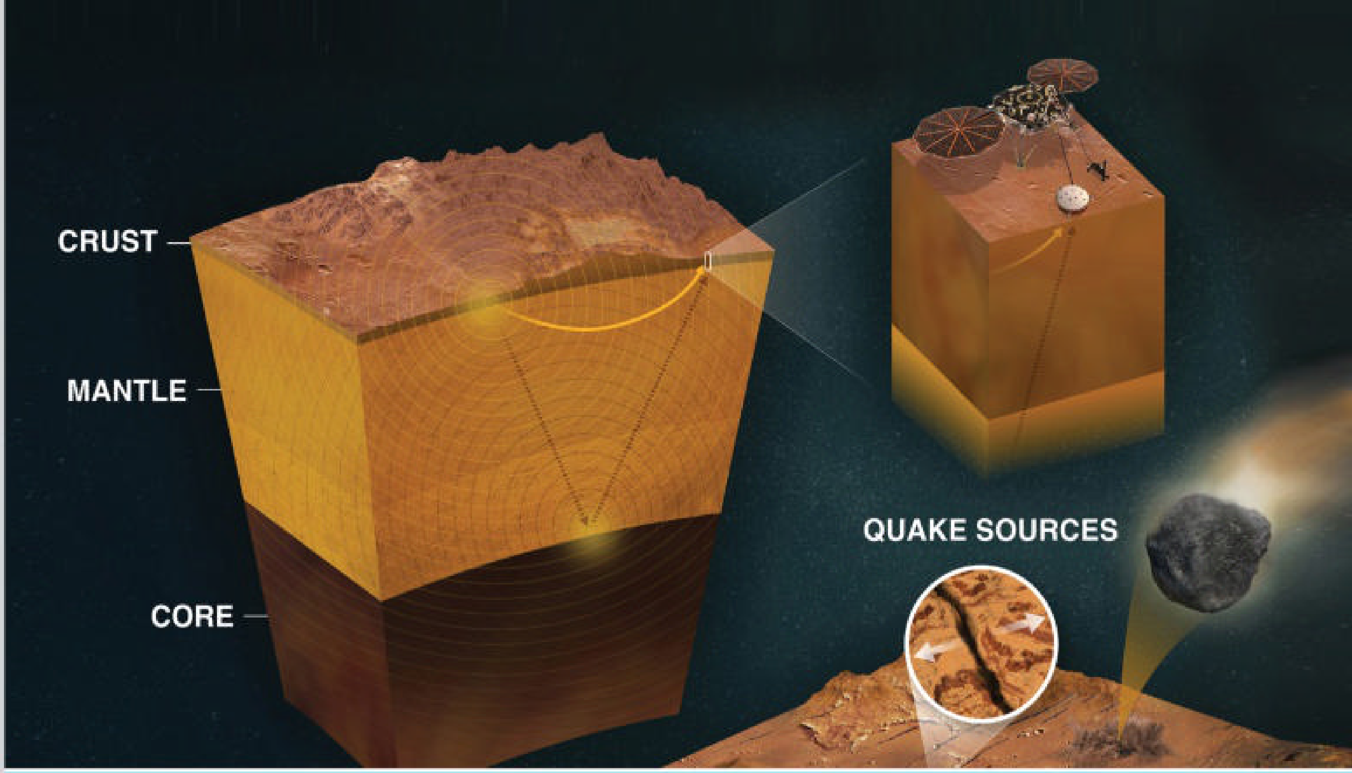
The sounds the scientists studied didn't come from natural processes on the planet itself. When a laser on the rover's SuperCam vaporized a nearby rock of interest to study its elemental composition, it generated a high-frequency sound wave that was caught by the microphone. Since scientists knew the distance to the rock and the time that the sound traveled, they could readily find its speed. SuperCam's microphone also recorded low-frequency sounds from the Ingenuity helicopter, hovering nearby.

Chide says the acoustic studies and other atmospheric data will help NASA design more accurate models of the martian atmosphere. Sound recordings can enrich studies of other extraterrestrial events, too, like the swirling vortices that race across the planet's surface and lift dust into the atmosphere.

The study was the first of many forthcoming analyses that will use sound waves to better understand alien worlds. "We have a lot of new information, and new data," Chide says. "Planetary acoustics is becoming a new field for exploration."

— STEPHEN ORNES

SOUND ON MARS
Scan the code with your phone for more on Mars audio.



SEISMIC SIGNALS from quakes change as they pass through different materials. NASA's InSight lander studies them in real time to parse the inner layers of Mars.

NASA/JPL-CALTECH

INSIGHT'S LAST DAYS CAPTURE THE LARGEST MARSQUAKE EVER

"THE BIG ONE" DELIVERS A WELCOME SHOCK TO PLANETARY SCIENTISTS.

For years, NASA's InSight lander has been shaking up what we know about geologic activity on Mars. After landing north of the equator in 2018, InSight began collecting data on marsquakes using a seismometer it carried to the Red Planet; since then, it has recorded more than 1,300 small quakes. The dome-covered device is not only the first seismometer to be directly placed on the martian surface, but also the first to record tremors on another planet.

In May 2022, the lander felt the largest quake ever captured on another world. Estimated to have been magnitude 5 on the terrestrial Richter scale, the marsquake was nearly 10 times more powerful than the previous record-holder. Earth experiences hundreds of such earthquakes each month, but on Mars, they seem to be a rarity. This is likely because our celestial neighbor lacks evidence of active plate tectonics. Unlike our own planet, there is no evidence of shifting masses of martian crust to generate marsquakes today. What caused the May quake has yet to be determined, but even objects long thought geologically "dead," like our moon, have occasional temblors as their rocky interiors continue to cool.

THE MARSQUAKE WAS NEARLY 10 TIMES MORE POWERFUL THAN THE PREVIOUS RECORD-HOLDER.

The quake's point of origin also remains elusive, though InSight data tells us that many of the largest marsquakes rumble through the region of Cerberus Fossae, almost 1,000 miles northeast of the landing site. Deposits of lava and ash suggest the area has experienced volcanic eruptions in the past 2 million years. Whether these more recent tremors are related to ongoing activity there is something that planetary scientists are eager to explore.

Sadly, InSight may be reaching the end of its life on Mars. Dust on the lander's solar panels has severely decreased the power they can generate, leaving InSight limping. NASA engineers programmed the lander to operate the seismometer until its battery drops to a level that permits only occasional photographs and communication with Earth, estimated to happen in the near future unless a propitious dust devil clears the dirt off.

Even so, the four-year mission on Mars has more than delivered on its promise to parse the internal structure of the Red Planet, as well as pave the way for a new generation of seismometers destined for our moon and Saturn's moon Titan. "Even though the mission is ending," says Wendy Bohon, a geologist at the Incorporated Research Institutions for Seismology in Washington, D.C., "the data InSight produced will continue to provide answers for years to come." — ERIK KLEMETTI

PERMAFROST NEARS TIPPING POINT

FROZEN PEAT BOGS STORE BILLIONS OF TONS OF CARBON AROUND THE GLOBE. WHAT HAPPENS WHEN A WARMING CLIMATE RELEASES IT?

A RESEARCHER MEASURES PEAT EMISSIONS IN FINLAND

THERE IS a time bomb sealed in the planet's frozen wastes. Scientists in the U.K. have found that by 2060, human-induced climate warming will likely thaw three-quarters of the far-north peatlands found in Scandinavia and western Siberia. If this happens, they warn in a March study published in *Nature*, an enormous amount of stored carbon, methane and other greenhouse gases could be released. That might fuel a cycle of more warming, more permafrost thawing, and so on. In this scenario, it is unlikely that permafrost in European peatlands would recover during this century.

Peatlands are areas where organic matter has died and piled up over eons in an environment so perpetually soggy that decomposition slows to a snail's pace. Like coal and other fossil fuels, peat contains compressed carbon from millions of years of solar energy stored in dead matter.

Though they are notoriously tricky to map — requiring field observations across vast areas — peatlands cover approximately 1.4 million square miles globally, according to rough estimates. That expanse, larger than India, holds approximately 415 gigatons of carbon, or as much as is stored in all the world's forests and trees combined.

"These peatlands have cooled the planet for over 10,000 years, but now we are pushing them over a threshold where they will begin to warm the climate instead," says Gustaf Hugelius, a Stockholm University expert in permafrost and global carbon cycling, who was not involved in the latest study. He describes the findings as "independent confirmation" of an emerging view that permafrost in western Eurasia is vulnerable even under relatively low levels of global warming.

Soggy peat bogs and fens are often associated with Scotland, where smoke from roasting the turf flavors the country's beloved Scotch whisky. However, they also occur in tropical zones and patches of Africa, Southeast Asia and South America. The resource is regularly excavated for fuel, damaged by logging and drained to make room for agriculture — all of which releases its stored carbon. Wildfires also pose the same threat, as in 2015 when a fire sweeping through Indonesian peat swamp forest emitted more CO_2 each day than the whole of the U.S. economy.

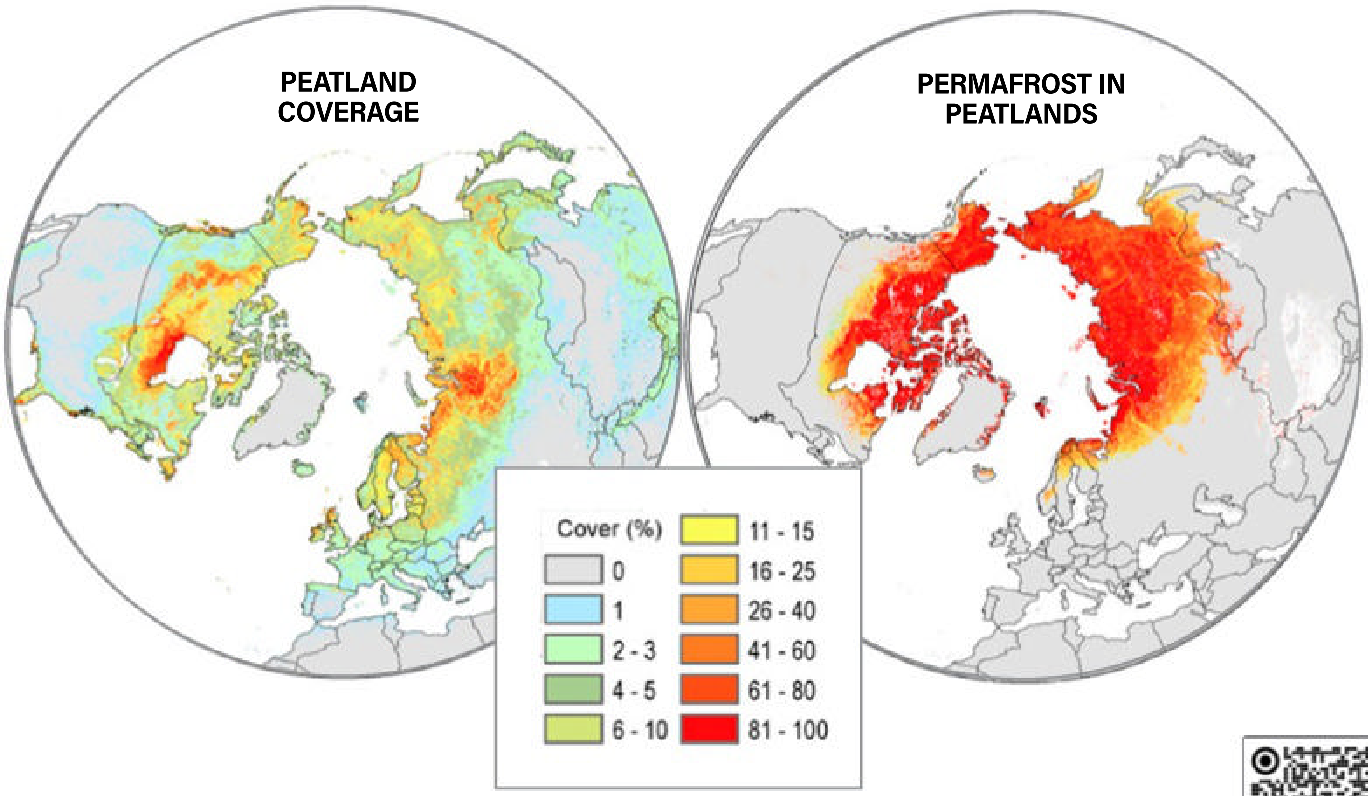
ULTIMATELY, though, it's far-north bogs that most concern Richard Fewster, a geographer at the University of Leeds in the U.K. and lead author of the 2022 study. They contain frozen permafrost in boreal forests and arctic regions that stretch from northern Europe to western Siberia. The extent of their potential global impact has emerged thanks to recent advances in remote peatland mapping.

Modeling shows that a warming of 2 degrees Celsius (3.6 degrees Fahrenheit) above preindustrial levels would cause some 270,000 square miles of peatland permafrost to thaw along its southern limit. Likely unfolding over several decades, it could be enough

DRY PEATLANDS in parts of Indonesia have fueled severe wildfires in recent decades, including a major event in 2015 that lasted nearly three months.

CLOCKWISE FROM TOP LEFT: SANTIAGO URQUIJO/MOMENT VIA GETTY IMAGES; F-FOCUS BY MATI KOSE/SHUTTERSTOCK; ULET IFANSASTI/GETTY IMAGES NEWS/GETTY IMAGES ASIAPAC

PERMAFROST IN western Siberia and Scandinavia has helped sequester carbon in peatlands for millennia.



NORTHERN PEATLANDS, which are often frozen in permafrost, hold about 80 percent of Earth's peat-stored nitrogen and carbon.

to shift frozen bogs from a net carbon sink to a net carbon source.

Fewster cautions that the exact impact is difficult to project due to myriad variables. For instance, "warming climates are likely to increase plant productivity across northern high latitudes, which could offset these losses to some degree," he says, adding that the rate of thawing is ultimately up to us.

We could keep 13.9 gigatons of carbon locked in icy permafrost if we committed to strict and immediate reductions in greenhouse gas emissions and bring net CO_2 emissions into the negatives by 2075. But, based on political and industry sentiments globally, that's a lofty mark. And time is running out.

"Unfortunately, there is no engineering or ecological-restoration solution that can alleviate the widespread collapse that global warming is causing in permafrost peatlands," Hugelius says. "The only solution is to limit global warming rapidly."

BEYOND SOIL
Scan this code with your phone's camera for more: How peat, scotch and UN climate talks are intertwined.

Environmentalists are rewetting drained peatlands and protecting others via conservation programs. And some scotch makers, in a gesture worthy of a toast, have started pledging to source their peat without damaging vulnerable ecosystems. — STEPHEN ROBERT MILLER

CHAT BUBBLES

SCIENTISTS ARE FINALLY TUNING IN TO THE CACOPHONY OF SOUNDS THAT FISH USE TO COMMUNICATE — AND NOW YOU CAN, TOO.

The past year saw a flurry of research documenting a phenomenon that fishers and scientists have known for centuries: Fish are surprisingly chatty creatures. "If you think about a lot of fish common names, [like] croakers and grunts," says Audrey Looby, a doctoral candidate at the University of Florida, "all those types of fish are named after the sounds they make to communicate." One such creature, dubbed the pigfish, even snorts like a pig, she adds.

Yet these fish have long been considered outliers, says Cornell University biologist Aaron Rice. He's one of the scientists challenging that assumption. In a study published in January 2022, Rice mapped sound-producing species onto a family tree and showed that at least 175 families of ray-finned fishes — the largest and most diverse fish group — contain a species that communicates via sound.

Meanwhile, Looby co-led efforts to create the *FishSounds* website (fishsounds.net). The first of its kind, this digital library of recordings could help researchers understand fish behaviors, track invasive species and monitor overall ecological health. Given the dire state of aquatic ecosystems, that can only be a good thing. And for non-experts, it's great fun to browse through the different noises, including "chirp," "jackhammer chorus" and "boop." — KATE GOLEMBIEWSKI

FROM TOP: GUSTAF HUGELIUS, ET AL/BOLIN CENTRE DATABASE; SEMET/ISTOCK VIA GETTY IMAGES

THE 2022 ERUPTION left only small remnants of the Hunga Tonga and Hunga Ha'apai islands above the ocean surface.

TONGAN BLAST FELT ACROSS THE GLOBE

An unexpected volcanic eruption sends shock waves around the planet, generating distant tsunamis and causing the atmosphere to vibrate for days.

» **ONE DAY PRIOR,** the 3-mile-wide plume of ash and vapor drifting above the South Pacific had been merely a blip on a weather satellite image. But in the early evening of Jan. 15, 2022, Hunga Tonga-Hunga Ha'apai exploded into the largest volcanic eruption in more than 30 years.

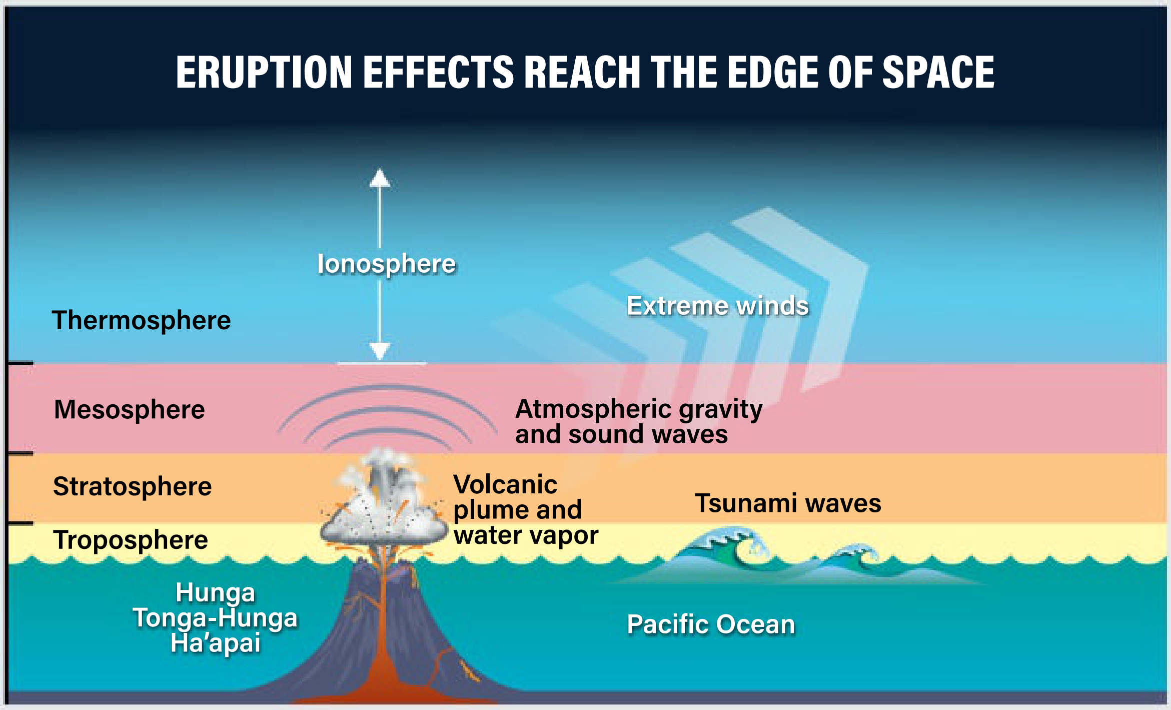
The blast blanketed most of the nearby Kingdom of Tonga in centimeters of ash, contaminating and destroying food and fresh water supplies. Waves up to 50 feet high devastated many of the country's roughly 36 inhabited islands, leaving them bereft of houses, and four people perished. Despite Tonga's high level of tsunami preparedness, the damage will be long-lasting and costly to repair.

Hunga Tonga-Hunga Ha'apai also sent a tsunami racing across the Pacific Ocean and ash hurtling into the stratosphere; the plume rocketed to 100,000 feet within about half an hour, throwing out millions of cubic feet of ash and volcanic debris per second. These ash particles rubbed against each other at high speeds, building enough electric charge to produce almost 400,000 lightning strikes.

Meanwhile, the sonic boom that accompanied the explosion could be heard as far away as Alaska. Researchers around the globe tracked its atmospheric shockwave, moving at almost 1,000 feet per second, for days afterwards. The rapid pressure changes even generated a worldwide tsunami, the first such event to be recorded by modern instruments.

"I remember seeing the satellite footage and being in absolute awe and disbelief," says Melissa Scruggs, a volcanologist at the University of California, Santa Barbara, who contributed to one of the first studies of the shockwaves generated by the blast.

Those familiar with Hunga Tonga-Hunga Ha'apai know that it's capable of small explosive eruptions, usually helped along



ERUPTION EFFECTS REACH THE EDGE OF SPACE

FROM TOP: TONGA GEOLOGICAL SERVICES/WIKIMEDIA COMMONS; KELLIE JAEGER/DISCOVER

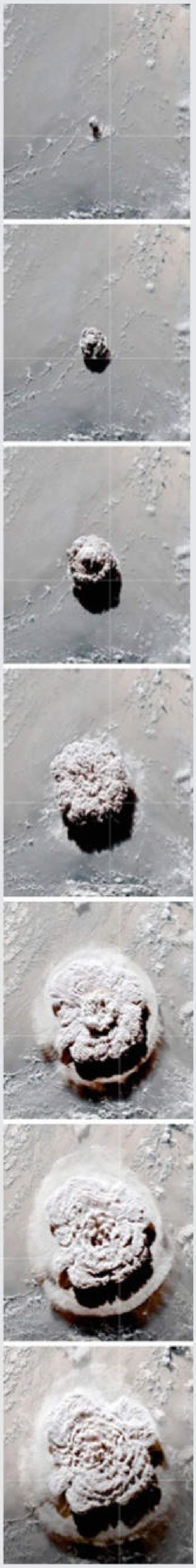
by the violent mixing of seawater and magma. Last year's blast, however, was much larger than anything on record for the submarine volcano. Volcanologists have compared it to the 1991 eruption of Pinatubo in the Philippines that damaged over 70,000 homes, and even the Krakatau blast in Indonesia that killed more than 36,000 people in 1883.

IT'S UNCLEAR what the potential climate impact of the Tongan eruption will be. Although the blast was one of the largest on record, the amount of sulfur dioxide — an aerosol that can contribute to global cooling by blocking solar radiation — released was only around 2.4 percent of that released during the 1991 Pinatubo blast.

However, researchers at NASA's Jet Propulsion Laboratory estimate that the volcano also ejected more than 146 million tons of water into the Earth's stratosphere — enough to fill almost 500 oil supertankers. This could cause the planet's surface to warm over time, thanks to water's longer atmospheric lifetime and potent power as a greenhouse gas.

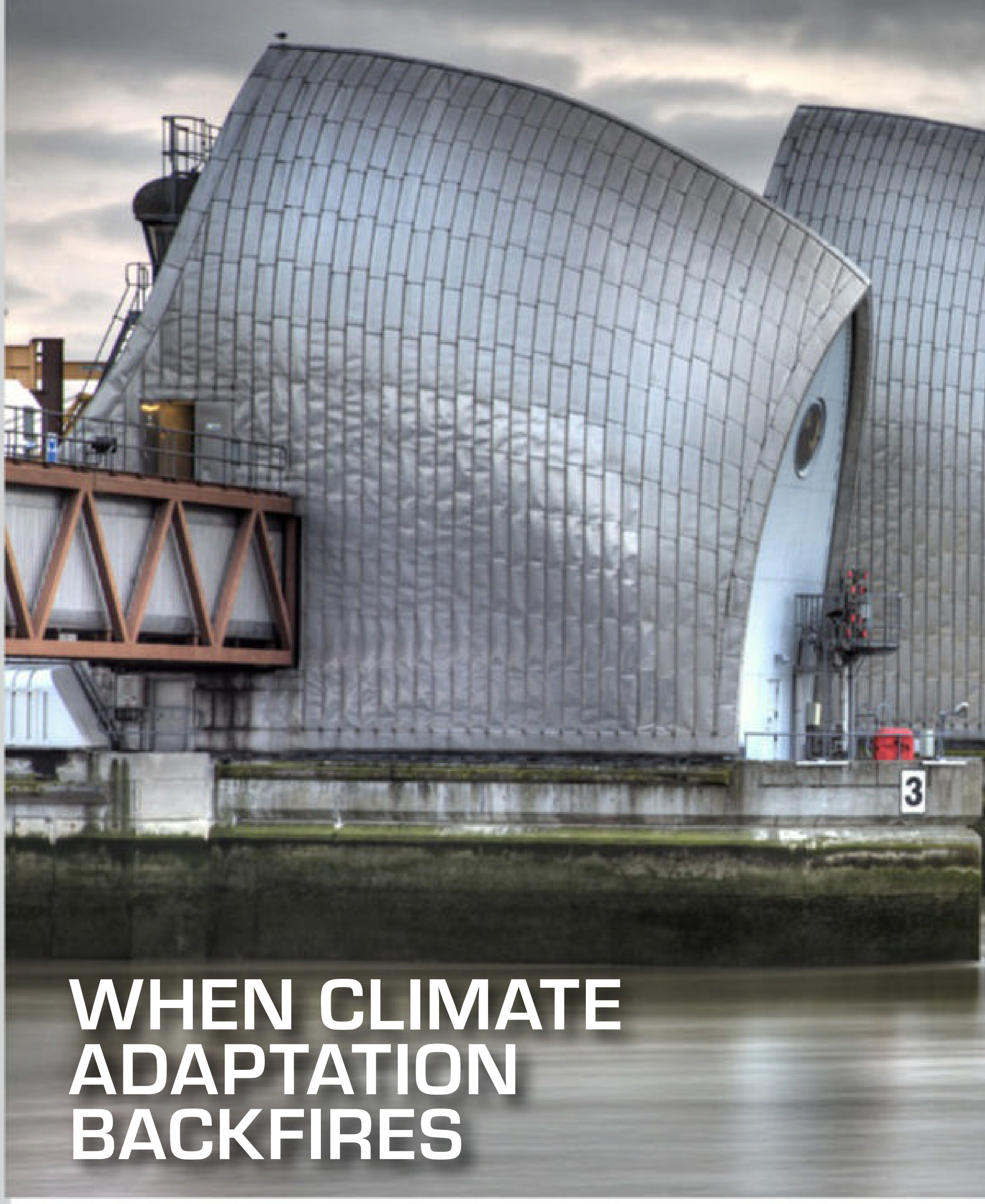
"[Though] the precise magnitude of any warming is still unclear," says Simon Carn, a volcanology professor at Michigan Technological University, "it is unlikely to be hugely significant in the context of anthropogenic climate change." Even so, the ejection will help volcanologists and climate scientists alike understand the climate impacts of explosive submarine volcanoes.

The biggest question on their minds: Why did Hunga Tonga-Hunga Ha'apai erupt so violently? "[It] highlights the volcanic hazard shallow submarine vents can pose," Scruggs says, referring to the potential for water and magma to mix at shallow depths and drive explosive blasts. If that is what fueled the event, then myriad volcanoes sitting just below sea level around the world could be a greater threat than previously thought. — ERIK KLEMETTI



SCIENTISTS VERIFIED the height of the plume by measuring the length of the shadows that taller clouds cast on broader ones below.

ERUPTION SERIES: COURTESY OF NOAA AND NESDIS



WHEN CLIMATE ADAPTATION BACKFIRES

In the scramble to combat climate change, so-called solutions can cause more harm. An IPCC 2022 report warns of these maladaptations.

AROUND THE WORLD, people are building levees, shoring up dams, digging canals and constructing infrastructure to confront the impacts of climate change. Most of these investments will likely save countless lives and protect property, but some will inadvertently add to the problems they are trying to address.

Experts call this phenomenon maladaptation. It generally refers to a protection effort against the impacts of climate change that backfires and increases vulnerabilities. For years, maladaptation was given short shrift as research and policy prioritized mitigating climate change by reducing greenhouse-gas emissions. Now, with the world lagging utterly behind that effort — in the U.S. alone, reports in 2022 showed that global warming could cost $2 trillion by 2100 — adaptation and its hazards are getting a hard look. This past spring, the proposed U.S. federal budget for 2023 earmarked $18 billion to make communities more resilient to climate change.

"Given the increasing impacts of climate change, adaptation is a must. At the same time, global warming is a very real limit to adaptation strategies," says Lisa Schipper, a climate researcher at the University of Oxford. She contributed to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change that outlined this risk in February of 2022. The researchers reported that once global average temperatures rise

SOME CLIMATE MITIGATION efforts, like London's Thames Barrier for flood control, carry steep costs. Others contribute to new hazards.

→ 2022 IN BRIEF

Massive Earthquake 3,800 Years Ago

Geologists used computational models and archaeological findings to show in an April study that a 9.5-magnitude earthquake struck Chile 3,800 years ago. The quake ranks among the largest in recorded history (tied with a 1960 quake, also in southern Chile); it was so disruptive that South American hunter-gatherers abandoned the coastline for an entire millennium.

by a further 1.5 degrees Celsius (2.7 degrees Fahrenheit), some adaptation efforts will be useless and others will be detrimental. One common example of such measures involves large development projects proposed to protect coastal cities.

In France, dikes built to protect low-lying communities from sea-level rise have backfired. As climate change speeds erosion, the seawalls have disrupted natural beach accretion and trapped river sediment so that less of it is delivered to the coast. The expensive infrastructure must now be rebuilt — repeatedly — to keep up with the changing coastline.

"Adapting to the current climate is not necessarily what you want to do for the future climate," says William Travis, a geographer at the University of Colorado Boulder. But that's often what happens. Plans for longer canals or higher seawalls might assume climate change will bring a linear increase of impacts, rather than new iterations of hazards at different frequencies and intensities.

"It's not just that something goes a bit wrong," Schipper says. Critical maladaptation "undermines opportunities for future adaptation, and that's what we should be looking out for."

ONE OF THE most insidious aspects of maladaptation is the false sense of security it gives. The U.S. population is concentrated into some of the country's most hazard-prone areas, like mountain forests and coasts. Erecting protective infrastructure in some of those places can cause people to downplay the risk, resulting in the "levee effect," Travis says. "Losses actually increase over what you would have if you hadn't built the infrastructure in the first place." Insurance and disaster assistance also tend to invite people to invest in harm's way.

Avoiding maladaptation requires a holistic approach and a long list of malleable strategies that allow us to alter course as needed, Schipper says. The old way, of taming nature with hardened concrete, is ill-suited to climate change.

The February IPCC report suggests avoiding investments we'll later regret. Specifically, it recommends strategies that serve more than one group and plan for the uncertainty of the future.

IN FRANCE, DIKES BUILT TO PROTECT LOW-LYING COMMUNITIES FROM SEA-LEVEL RISE BACKFIRED.

In California, a number of water agencies have started to use an analytic framework called robust decision-making. The advanced tool could help preserve the state economy while California's booming ag sector and city populations compete for scarce water supplies. Applying the tool in the San Bernardino Valley, managers played out 1,872 plausible futures to find a sweet spot between slashing water to irrigation and importing new supplies, all while testing unforeseen disruptions to the system.

Schipper worries that many current climate responses perpetuate inequalities, often by imposing foreign systems and technologies on vulnerable people. In coastal Bangladesh, for example, introducing Dutch-inspired levees in rivers has left millions dependent on unmaintained and ill-suited infrastructure.

Cheaper, nature-based solutions, like rehabilitating wetlands that absorb flooding rivers, can work better than glitzy techno-solutions in some places. But these fixes are often overlooked, especially if on-the-ground knowledge about the environment is ignored. Prioritizing local perspectives in discussions can address that.

"By solving one problem, we almost always create another problem, and it's always the poorest people who suffer," Schipper says. "We have to acknowledge that there will always be trade-offs. There are no silver bullets." — STEPHEN ROBERT MILLER

TOP: MARC PINTER/SHUTTERSTOCK; SK HASAN ALI/SHUTTERSTOCK

THIS MOTH'S new name is inspired by its fluffy masses of eggs and silk, which can house up to 1,000 offspring at once.

RENAMING NATURE

The spongy moth got a new name because its previous moniker contained an ethnic slur. It's part of a larger trend of rechristening organisms and institutions. But does it make a difference?

MAGDA MATACHE was “devastated” when she first heard the common name for *Lymantia dispar* — the gypsy moth. It's a term that Matache, a Roma activist and the director of the Roma Program at Harvard University's FXB Center for Health and Human Rights, says carries “a very painful historical weight.”

In March 2022, the Entomological Society of America recognized that reality when it announced that *L. dispar* would now be known as the spongy moth. It joins a growing group of organisms and scientific institutions that have been renamed because their old monikers either contained offensive references to groups of people, or honored individuals who committed human-rights abuses.

Still, the choice to rechristen was not made lightly, says Jessica Ware, associate curator at the American Museum of Natural History's department of entomology and president of the Entomological Society of America. While some scientists argue that these questionable names hold historical significance or that their offensive natures may be unintended, others maintain that those caveats don't justify their damaging effect.

The spongy moth's old name was likely in reference to the brown color of the male moth, said to resemble the skin color of the Romani people, who were enslaved in parts of Eastern Europe for nearly five centuries. While slavery was abolished in and around what is now Romania by 1856, the Roma have continued to endure prejudice and genocide — as well as the pejorative G-word that has become an analogue for free-spirited travelers or wanderers in pop culture. “It's not our name; it's actually a racial slur,” Matache says.

NAME CHANGES ARE MERELY ONE STEP TOWARD GREATER EQUITY IN SCIENCE.

The moth's moniker had been in common parlance since at least 1908, most recently due to its status as a pest in the eastern U.S. There, hordes of the species' caterpillars devastate forests by feasting on tree leaves. From 2000 to 2019, they defoliated more than 17 million acres in the region, despite the creation of a national program at the turn of the century to slow their spread.

IN 2020, the ESA received a request to remove the offensive name. The society's Better Common Names project formed a working group to rename the moth and a similarly named ant the very next year. That task force included scientists, scholars and members of the Romani community, who came together to build a case for the change. Beyond just removing the slur in the insect's title, the team worked to pick a name that had nothing to do with the Romani people. “I think it's so important that we shift away from this process of dehumanization,” says Matache. They settled on *spongy moth* because of the spongelike clumps of eggs and silk that the moth deposits on tree trunks.

This reconsideration isn't an isolated event: The ESA

FROM TOP: HEATHER BROCCARD-BELL/E+ VIA GETTY IMAGES; MARTYNOVA ANNA/SHUTTERSTOCK

renamed the Asian giant hornet (now known as the northern giant hornet) in July to combat xenophobia. And in 2020, a small prairie bird named after John P. McCown, a Confederate general who also harmed Indigenous people, was rechristened the thick-billed longspur.

BEYOND INDIVIDUAL species, some scientists have raised questions about problematic namesakes of entire biological institutions. Wildlife biologist Corina Newsome recalls learning that famed ornithologist John James Audubon was an enslaver the day she took a job at Georgia Audubon. "I was filled with guilt," she says. "I was like, 'How can I work for an organization that is literally named for someone who enslaved my ancestors?' "

Newsome, who now works for the National Wildlife Federation, notes that name changes are merely one step toward greater equity in science. While the slur in the spongy moth's old name was in dire need of replacement because it immediately registered as offensive, she argues that in many cases, a name change isn't necessarily at the top of the to-do list. Instead, Newsome hopes that people in charge of problematically named organizations "address the structural issues that are embedded into the way they operate," including decisions about investments, hiring and community engagement.

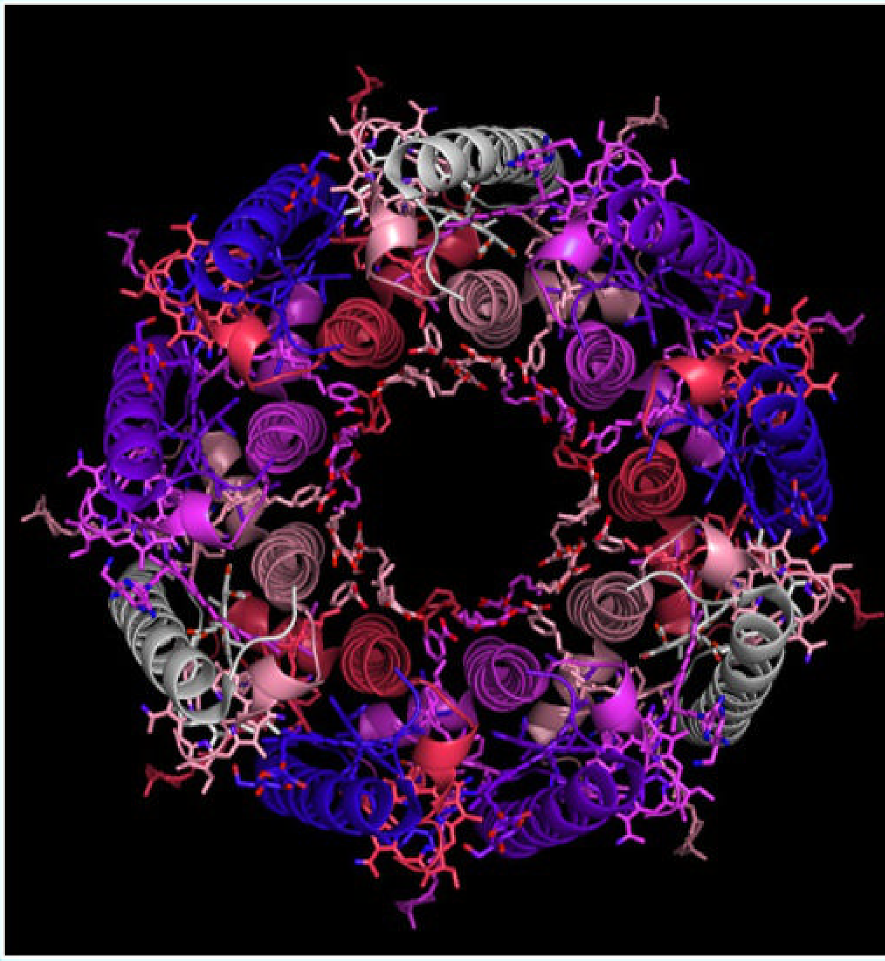
Ware agrees that "it would be a shame to think that people would rally behind just a name change and not do any of the other things that go along with it." However, she says, "we as scientists have a responsibility to create the type of scientific community where everybody is able to participate equally, and also to respond to mistakes that we've made in the past."

— KATE GOLEMBIEWSKI

FROM TOP: IAIN JOHNSTON; FIONA M. DONNELLY/SHUTTERSTOCK

SOLVING LIFE'S SYMMETRY

COMPUTER SCIENCE EXPLAINS WHY THE EVOLUTIONARY DECK IS STACKED IN FAVOR OF SYMMETRICAL OPTIONS.

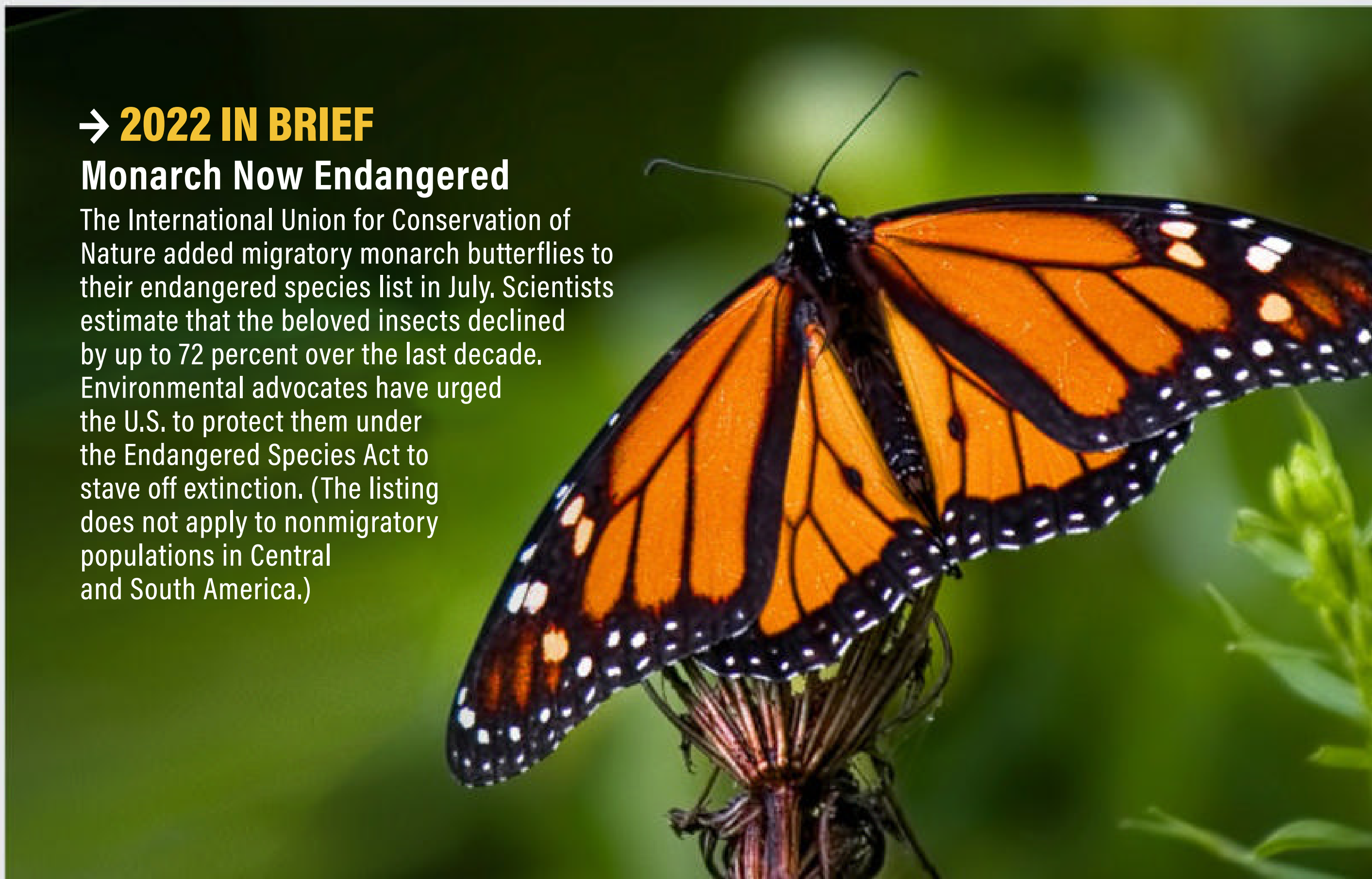


A NEW THEORY suggests why so many moleculular components, like this light-harvesting complex taken from a bacterium, are naturally symmetric.

From mirror-image butterfly wings to the repeating fractal patterns of fern fronds, most living things display some kind of symmetry — yet the reason why has remained a mystery. In March, a paper published in the *Proceedings of the National Academy of Sciences* offered an explanation: Evolution tends toward symmetry because it's easier.

While simulating the formation of viruses' protein shells, researchers noticed that symmetrical shapes cropped up much more frequently than pure randomness might suggest. To a computer programmer, however, this makes sense: It's easier to encode instructions for a simple shape and repeat that than it is to come up with loads of complex, one-off directions.

The researchers, led by University of Oxford physicist Ard Louis, realized that the same logic applies to the genetic instructions in living things. "Things that can be described with short descriptions are just going to appear more often," he says. Though the *PNAS* study focused on tiny structures like protein complexes, its authors believe the same principle could explain the phenomenon on larger scales too — including the oft-coveted bilateral symmetry of human faces and bodies. — KATE GOLEMBIEWSKI



→ 2022 IN BRIEF

Monarch Now Endangered

The International Union for Conservation of Nature added migratory monarch butterflies to their endangered species list in July. Scientists estimate that the beloved insects declined by up to 72 percent over the last decade. Environmental advocates have urged the U.S. to protect them under the Endangered Species Act to stave off extinction. (The listing does not apply to nonmigratory populations in Central and South America.)

HOOFED MAMMALS may be more likely to pass diseases to humans because of their close proximity to us.

SAKDAWUT TANGTONGSAP/SHUTTERSTOCK

WELCOME TO THE PANDEMICENE

Spillover of animal diseases to humans is on the rise, spurred by climate change and habitat destruction that forces people and wildlife to share close quarters.

COVID-19 IS NOT the first disease to migrate from animals to humans. The Black Death of the 14th century was spread by fleas that feasted on rats infected with the *Yersinia pestis* bacterium. The H1N1 virus behind the influenza epidemic of 1918 originated in birds. The list goes on.

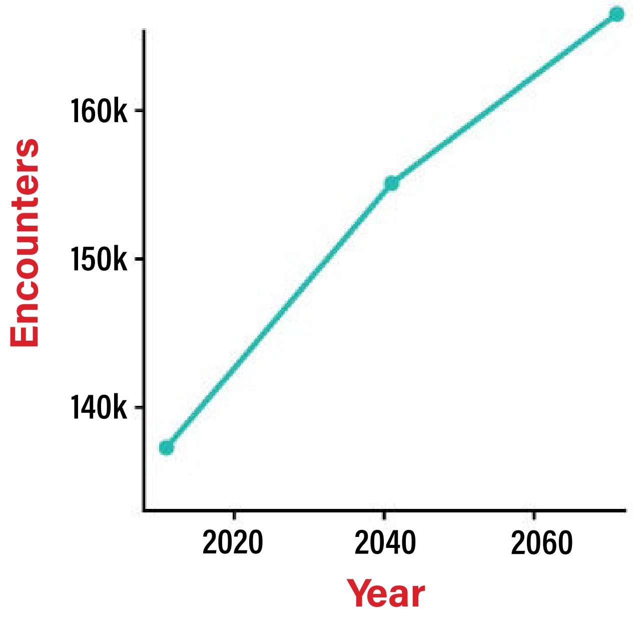
There was a time when these outbreaks were relatively infrequent, but today, some three-quarters of new infectious diseases emerge from animals. In the last two decades alone, we've been hammered by zoonotic outbreaks, including SARS, swine flu, MERS, Ebola, bird flu, and most recently, COVID-19 and monkeypox. (See the story on page 45.) Some researchers have taken to calling this era the Pandemicene, or the age of pandemics. A study published in *Nature* in April suggests a likely culprit: climate change.

"The study comes from a pretty simple idea," says Colin Carlson, a global change biologist and a lead author of the paper. Climate change is rendering many habitats inhospitable. When animals migrate toward cooler climates, they introduce viruses to new environments and new neighbors. "That leads to interesting problems from a viral standpoint," says Carlson.

To predict displacement patterns, Carlson and his colleagues taught machine-learning models the kinds of habitats used by different

3 OUT OF EVERY 4
NEW OR EMERGING INFECTIOUS DISEASES IN PEOPLE COME FROM ANIMALS.

MEETING NEW NEIGHBORS



Even if global warming is held at 2 degrees Celsius, tens of thousands of displaced species are projected to meet for the first time over the next half-century.

Source: Carlson, Colin J., et al, "Climate change increases cross-species viral transmission risk," *Nature*, 2022

mammals. The modeling software then predicted, under a range of possible climate futures, where such conditions might be found in 2070, he explains. Many animals will head to cooler mountains, or to coastal regions with moderate climates; eastern China, Indonesia, the Philippines, India's Rift Valley, and Africa's Ethiopian highlands and Sahel region are all expected to have sky-high human population densities and biodiversity levels by the year 2070, making them vulnerable to outbreaks of zoonotic disease.

Carlson and his colleagues paired these predictions with a model that parses why different animals share viruses. The same flight capabilities that make bats excellent pollinators, mosquito-hunters and seed-dispersers, for example, also make them more likely to transmit diseases from one area to another. And while it's easier for viruses to spread between closely related species (for instance, gorilla to human), even viruses optimized to our distant relatives can find purchase in us, given enough opportunities for infection.

"The network of hosts and viruses is getting completely redrawn from scratch," Carlson says. He and his colleagues estimate that by 2070, there will be at least 3,000 instances of novel cross-species infection. Not all will directly affect humans, and not all will become pandemics — but some will.

Ecologists are already tracking animal migration patterns to anticipate potentially dangerous pathogens and hotspots. However, humanity's best chance of mitigating zoonotic pandemics likely lies in different decision-making and policy, according to Marguerite Pappaioanou. An epidemiologist and veterinarian at the University of Washington, Pappaioanou says focusing on tracking down diseases in the wild isn't terribly efficient: "The most effective way to stop future pandemics is to stop and prevent human interaction with animals. And that's doable."

MORE BROADLY, Pappaioanou advocates for the One Health model of health care, a collaborative approach that focuses on the underlying economic and cultural forces behind people's interactions with animals and the social circumstances that allow diseases to spread. The movement, which took off in the 1960s, has since been adopted by the World Health Organization and other international agencies.

"Part of this One Health picture is to bring in the social scientists to help figure out what we need to do to modify human behavior," Pappaioanou says. For instance, many zoonotic diseases emerge from animals that humans keep for food. An intervention for farms and live-animal markets might include personal protective equipment for workers. In other scenarios, cultural shifts include broadening testing for animal-spread diseases and even changing funerary practices for people who have died from highly contagious diseases.

A challenge of this approach is the intense need for collaboration. "This needs to happen all as part of one big plan, not sector by sector, silo by silo," Pappaioanou notes. "Unless you have everybody at the table, you're going to make some bad decisions [that might help in one area but] lead to disaster somewhere else."

For individuals, businesses and governments accustomed to acting independently and in their own best interest, such collaboration might prove a tall order — even in the face of a threat like climate change. But Pappaioanou maintains hope. "We know what to do. We have the information we need to prevent and stop future pandemics," she says. "The challenge is finding the political will." — KATE GOLEMBIEWSKI

FROM TOP: LIOBSY/SHUTTERSTOCK; ALIN LUNA/UNSPLASH; PENCIL CASE/SHUTTERSTOCK

THE MYSTERY OF LONG COVID

AS RESEARCHERS TRY TO FIGURE OUT WHAT CAUSES LASTING POST-COVID SYMPTOMS, MILLIONS OF AFFECTED PATIENTS ARE DESPERATE FOR ANSWERS.

IN MARCH OF 2020, there seemed to be two possible outcomes if you got COVID-19: You succumbed to it, or you ultimately recovered.

But months later, some symptoms were lingering far longer than people expected. Frequent joggers who'd caught COVID weeks before started to get winded walking down the block. A U.K. lawmaker stated on Parliamentary record that he was months into long-lasting viral fatigue. Even global sports superstars reported post-COVID malaise. "I came back and it was like a month and a half without even being able to run because my lungs were affected," soccer World Cup winner Lionel Messi told Argentina's TYC Sports this May.

As the pandemic drags into its third year, the number of people reporting long-COVID aftereffects continues to climb. As of June, almost 1 in 5 adults who contracted the virus were experiencing a range of long-COVID symptoms, according to a Centers for Disease Control and Prevention (CDC) survey. The ailments range from cognitive and concentration problems to shortness of breath, muscle pain and heart palpitations.

Globally, that translates to hundreds of millions of people struggling in a multitude of ways. "Long COVID is not only brain fog and fatigue," says Ziyad Al-Aly, a Washington University clinical epidemiologist and chief of research and development

→ **2022 IN BRIEF**

COVID-19 Deaths Climb

The coronavirus officially claimed its one-millionth U.S. victim in May — and some experts think that's an underestimate. The true toll, they say, includes many more undiagnosed COVID-19 cases, plus other deaths related to overwhelmed health care systems and canceled medical appointments. Under those criteria, the global death estimates are three times greater than reported, and the U.S. already passed the million mark back in 2021.

PILLI/SHUTTERSTOCK

at VA St. Louis Health Care. “It’s really a multifaceted disease that can affect nearly every organ system.” And though researchers have some theories about what drives it — ongoing inflammation and blood abnormalities are among the leading hypotheses — no one knows for sure what causes the condition, says Mayo Clinic infectious disease specialist Greg Vanichkachorn.

While long COVID’s origins remain mysterious, some of its effects show signs of being long-lasting, especially symptoms that involve brain and cardiovascular changes. In a March *Oxford University* study, people between the ages of 51 and 81 who previously had COVID showed substantial deterioration in areas of the brain like the hippocampus and parahippocampal gyrus, which play major roles in storing and retrieving memories. Those changes could help explain why so many long-COVID sufferers report brain fog and forgetfulness.

IN FEBRUARY, Al-Aly and his colleagues reported that people with past COVID infection were 63 percent more likely than controls to develop cardiovascular illness over a 12-month period. Most post-COVID heart conditions Al-Aly sees in the clinic are manageable, he says. “But they’re chronic in nature. They don’t reverse themselves.”

Though anyone who’s had the virus can suffer a constellation of long-term effects, some people are more susceptible than others. Those who have the most severe initial disease are more at risk of long COVID, studies show, as are people who have fewer virus-squashing antibodies in their blood after infection. (The only way you would know those levels is through an antibody-detecting blood test.) Getting the COVID vaccine does reduce your risk of long-term complications, but only modestly. Vaccinated people who develop COVID, Al-Aly has found, are about 15 percent less likely to develop long-COVID symptoms than unvaccinated people.

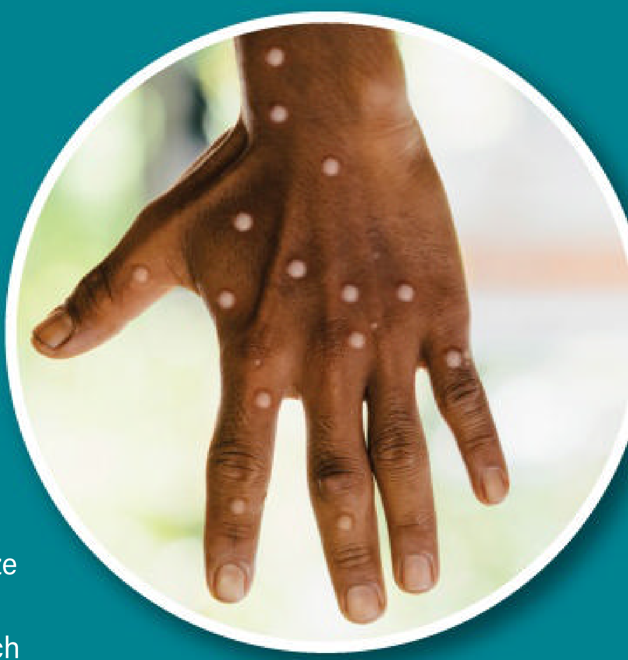
AS OF JUNE, ALMOST 1 IN 5 ADULTS WHO CONTRACTED THE VIRUS WERE EXPERIENCING A RANGE OF LONG-COVID SYMPTOMS.

The extended forecast for COVID long-haulers isn’t all pessimistic: Vanichkachorn estimates that about 1 in 5 people with long COVID recover completely within six months. For those who remain ill longer, the prognosis is less clear. Still, Vanichkachorn reminds his patients that researchers are just beginning to explore ways to treat the condition.

Figuring out the biological basis of long COVID will be a crucial step toward developing drug treatments that help patients return to normal life. But just as crucial, researchers say, will be fast-tracked clinical trials that identify which existing drugs can safely be used to treat the condition. “How many approved treatments do we have for long COVID? Zero,” Al-Aly says. “We need to solve this yesterday.” —ELIZABETH SVOBODA

MONKEYPOX GAINS GROUND

PUBLIC HEALTH OFFICIALS FEEL A SENSE OF DÉJÀ VU.



MIA STUDIO/SHUTTERSTOCK

THE CHARACTERISTIC MPX rash may initially appear like pimples or blisters that progress through stages, including scabbing, before fully healing.

» **In late July,** the World Health Organization declared monkeypox, or MPX, a public health emergency. On Aug. 4, the Biden administration followed suit in the U.S. The disease, characterized by fever, chills and a smallpoxlike rash, is rarely deadly, though symptoms may be extremely uncomfortable for weeks. (While primates are the only other mammal known to show symptoms when sick, the WHO abandoned the *monkeypox* moniker to minimize stigma toward people and animals.)

Scientists first discovered MPX in 1958 among research monkeys in a Copenhagen, Denmark, lab; the first known human case occurred in 1970 in the Democratic Republic of the Congo. Until last year, the disease rarely cropped up outside Central or West Africa, where it is endemic and likely harbored in rodents and other small mammals. By September, however, the disease had emerged in 84 countries outside Africa, including all 50 U.S. states. Upwards of 90 percent of these cases involved men who have sex with men — though the virus can spread to anyone through close contact with an infected person or contaminated surface.

The cause of the sudden spread remains unclear. And even as the window for containing the virus closed, the response to MPX was beset with problems. Experts say the U.S., in addition to garbling its messaging and contributing to global uncertainty about the populations at greatest risk, was slow to roll out testing and vaccine production. To stretch supplies, the government authorized a less common vaccination method that uses a fraction of the traditional dose.

“The response needs to be much more forward-leaning and much more rapid,” says Georges Benjamin, executive director of the American Public Health Association. He notes that the public-health sphere tends toward a methodical approach to managing outbreaks. Yet this new world, Benjamin says, with its multitude of emerging (and reemerging) infectious diseases, demands a different mindset. —AVERY HURT

SCIENTISTS FOUND *Endurance* in near-perfect condition and will study its contents for new insight into the original mission and crew of the vessel.

SHACKLETON'S SHIP FOUND

Scientists finally locate the 107-year-old shipwreck, deep within the Weddell Sea.

IN NOVEMBER 1915, polar explorers watched with gut-wrenching dismay as Antarctica's Weddell Sea swallowed their ship, *Endurance*. Ice had trapped and crushed the vessel "beyond all hope," mission leader Sir Ernest Henry Shackleton wrote. Now marooned on floating ice, the 28-man crew drifted from the continent it had hoped to traverse.

With supplies dwindling, the explorers paddled lifeboats to a desolate island and survived on seal and penguin meat. Shackleton and a few mates took one of the small boats, *James Caird*, and sailed over 800 miles across treacherous seas to bring back help. The crew's rescue came nine months post-wreck. All survived. Even *James Caird* made it back to England, where it is still displayed at a school in London. *Endurance*, however, remained lost — until now.

Last February, a team of scientists and other experts embarked in an icebreaker vessel to the spot where the original crew reported *Endurance* went under. Their mission: Locate the shipwreck, buried beneath the frozen sea.

Even today, cruising the Weddell Sea is a feat, with some areas of its surface over 90 percent frozen in the warmest months. "The ice there is very old and thick

CLOCKWISE FROM TOP LEFT: FALKLANDS MARITIME HERITAGE TRUST (3); ROYAL GEOGRAPHIC SOCIETY/WIKIMEDIA COMMONS

UNDERWATER DRONES helped the team scan the seafloor for the ship, which was crushed and submerged during an Antarctic voyage in 1915.

and very strong. That's the reason why Shackleton actually got trapped," says geophysicist Lasse Rabenstein, chief scientist for the expedition, which was organized by the Falklands Maritime Heritage Trust.

USING SATELLITE and meteorological data to plot the course, the expedition maneuvered around the ice floes. When they reached *Endurance*'s approximate coordinates, the researchers launched a set of state-of-the-art Sabertooth diving drones. Over three weeks and dozens of dives, these sedan-length submersibles surveyed and filmed the seafloor. In March, they found *Endurance* in spectacular condition — with its steering wheel, railings and ropes intact — about 4 miles away from the location estimates of the original crew and nearly 2 miles below the surface.

Though *Endurance* will remain submerged, 3D scans taken at the wreck will help marine archaeologists study the ship's construction and contents. The expedition "was also a big experiment," Rabenstein says, allowing researchers to test marine navigation technology and measure sea ice throughout the 35-day voyage. "All of this will feed into scientific data for climatologists and other scientists," Rabenstein explains. — BRIDGET ALEX

CLOCKWISE FROM TOP LEFT: ESTHER HORVATH; FABRICE DEMETER (2)

THE FOSSILIZED molar came from a cave in Laos' Annamite Mountains, located many miles south of the sites where all other undisputed Denisovan fossils had been recovered.

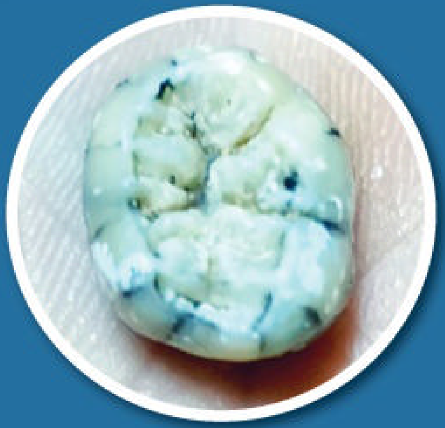
DENISOVAN TOOTH IN THE TROPICS

A RECENT FOSSIL FIND REVEALS A WIDE RANGE FOR A MYSTERIOUS HUMAN RELATIVE.

IN 2018, a researcher reached into his pocket and pulled out a tooth for Fabrice Demeter. The leader of an excavation in the Annamite Mountains in Laos, Demeter had sent the tooth-bearer and several others in search of fossils. The team returned toting fossil-filled rocks — and the molar.

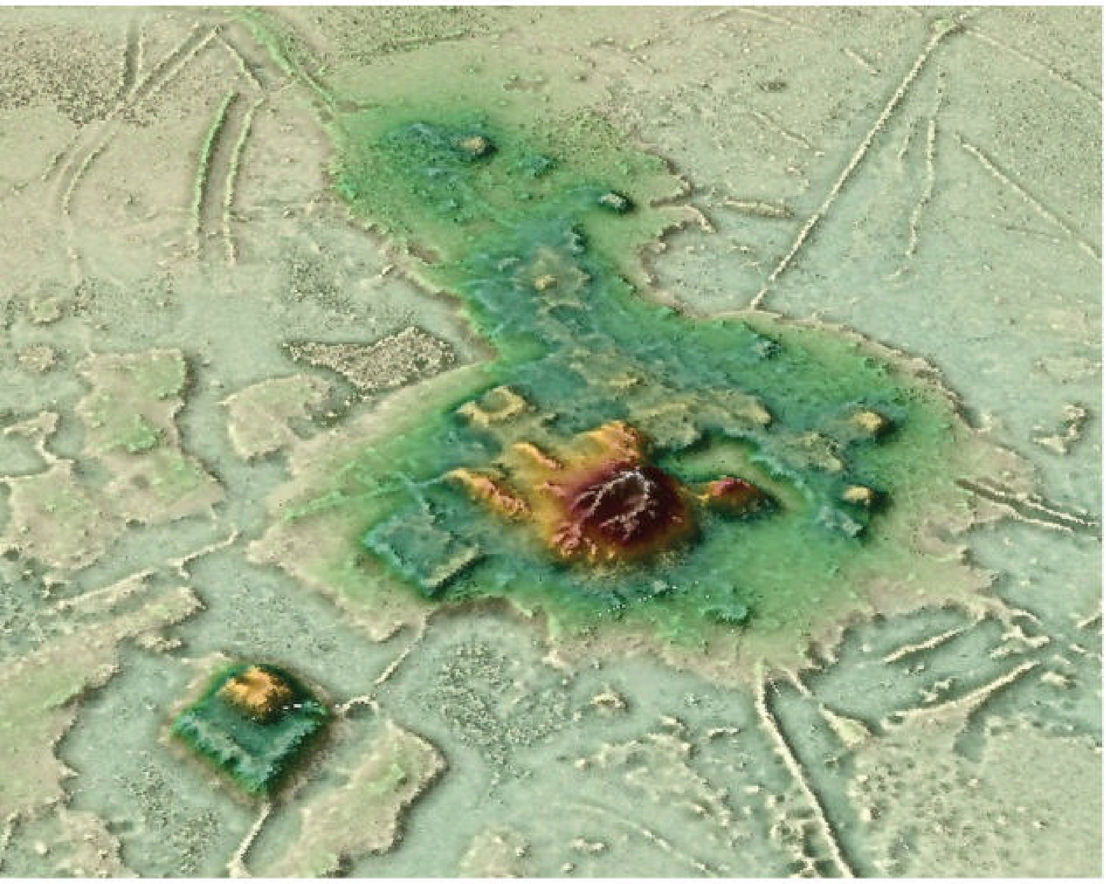
"Immediately I could tell it was a human tooth," recalls Demeter, an anthropologist at the University of Copenhagen, Denmark.

Over the following years, Demeter and colleagues used high-resolution CT scans to compare the tooth's shape, surface features and internal structure to the same measures from around 400 fossil humans. The molar looked like a bulky tooth from a Neanderthal, but that species has never been found so far from Europe. Identifying another possible match from a more mysterious lineage, the team's May *Nature Communications* analysis argues it came from a Denisovan.



Until the time of the publication, only five Denisovan fossils had surfaced: a pinky and three teeth in a Siberian cave and a partial jawbone on the Tibetan Plateau. But clues from Denisovan DNA, including its traces in living populations today, hint that they once occupied much of Asia, not just these two sites at high latitudes and elevations, respectively. Considering the Laos tooth's large size, rugged top and geographic origin, Demeter and colleagues contend it belongs in the Denisovan club, which means that these humans also survived the tropics.

The team has already detected proteins and growth markers suggesting the tooth came from a female between 3 and 9 years old, and they are now attempting DNA analyses to confirm her Denisovan ancestry. Dating of rocks and animal teeth from the cave indicate the child lived between 130,000 and 164,000 years ago, when at least four other human varieties roamed Southeast Asia, including modern humans. It's unclear how the groups got along, but the region was definitely "a hot spot for species," Demeter says. — BRIDGET ALEX



LIDAR CAPTURES elevations so precisely that its measurements between the Andes and the Amazon have exposed elaborate ancient settlements, previously concealed by 1,000 years of plant growth.

BROUGHT TO LIGHT

LIDAR REVEALS 1,000-YEAR-OLD CITIES COVERED IN VEGETATION.

THE ANCIENT site of Salvatierra, nestled in the floodplains between the Andes Mountains and Amazon forests, would've been a sight to behold. Built a millennium ago, the urban oasis boasted elevated buildings and earthen pyramids, as well as a complex system of canals and reservoirs capable of hydrating thousands of inhabitants and acres of maize during the peak of the South American dry season.

Today, the site looks like a mound of forest in the savannah of Bolivia. Decades of excavations have uncovered its ruins. And Salvatierra isn't alone — archaeologists have identified hundreds of similar mounds, thought to be inhabited between A.D. 500 and 1400 by the Casarabe culture. But only a handful have been seriously investigated due to the cover of dense vegetation.

To better understand these sites, researchers

FROM TOP: HEIKO PRÜMERS/DAI; MARK BRANDON/SHUTTERSTOCK

TWO NEW *TYRANNOSAURUS* SPECIES?

A CONTROVERSIAL NEW THEORY CHALLENGES THE IDEA THAT *T. REX* WAS ALONE.

For more than a century, *Tyrannosaurus rex* has stood as a singular species, a tyrant lizard king without peer. But in March 2022, paleontologists made a controversial proposal: There was more to *Tyrannosaurus* than just *rex*, they speculated, suggesting that two additional species had been hiding in plain sight.

Tyrannosaurus ruled for quite a long time and left behind significant fossil evidence. Dating approximately 65 million to 69 million years old, more than 50 partial *Tyrannosaurus* skeletons have been found. And paleontologist Gregory Paul and colleagues say some tyrannosaurs in this fossiliferous collection don't look quite like *rex*.

According to their *Evolutionary Biology* paper, paleontologists have uncovered at least three distinct types of *Tyrannosaurus*, suggesting two new species. *Tyrannosaurus imperator*, the bulky "tyrant lizard emperor," was the earliest of these species to arise and can be recognized by two small teeth at the front of the jaw. From this first species descended *Tyrannosaurus rex* and a more slender species called *Tyrannosaurus regina*, the "tyrant lizard queen," which lived alongside one another. Both of these species had only one small tooth.

Other paleontologists have criticized the hypothesis, generating at least one rebuttal study so far. "The problem for me centers around whether we know enough for these names to be useful," says San Diego Natural History Museum paleontologist Ashley Poust. Individual dinosaurs varied from each other, just as people do, so the subtle differences in tooth count and whether a skeleton looks slender is not enough to confidently establish new species.

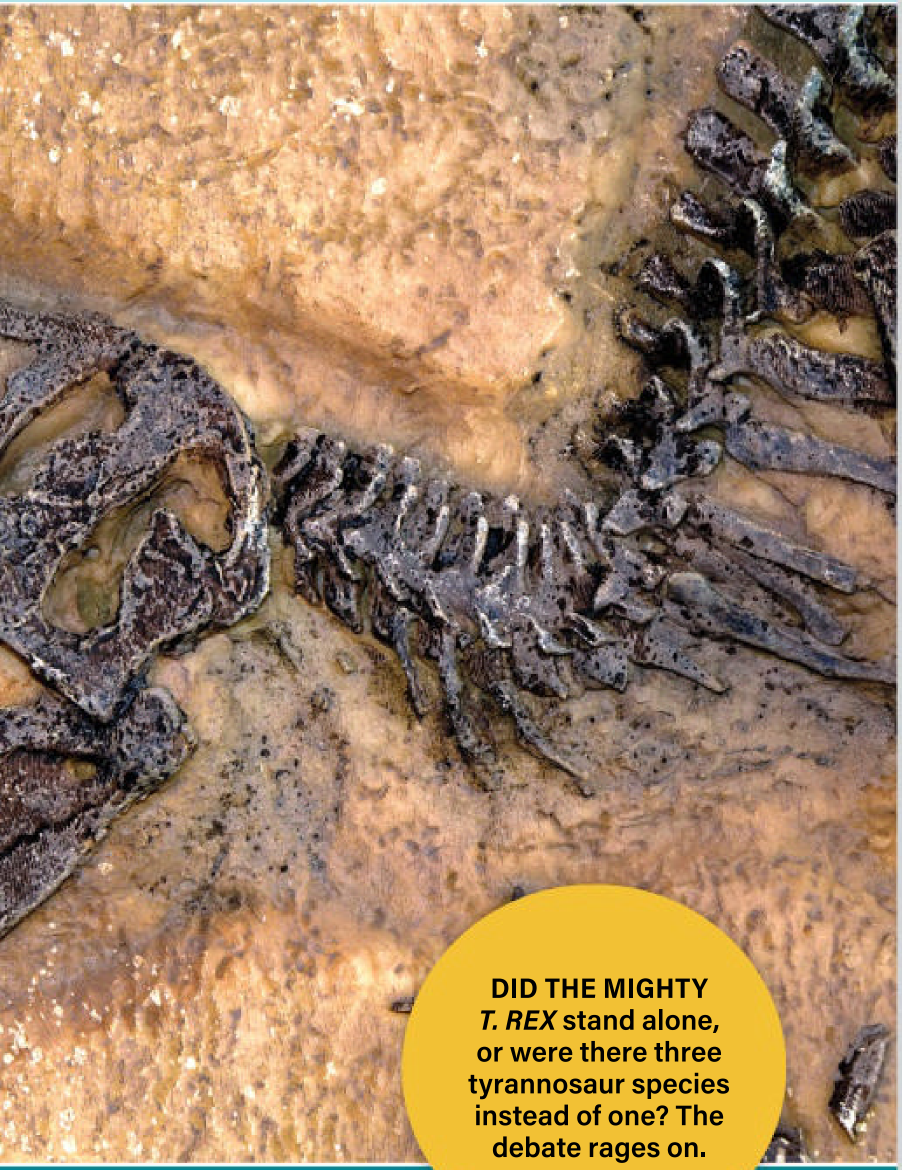
So far, *T. rex* still stands alone. "I have no problem whatsoever with there being multiple species of *Tyrannosaurus*," Poust says, but the evidence isn't convincing just yet. The truth will rely on future finds in the field and museums. "We're going to need a lot more fossils," he notes, "even fossils of animals we think we know." — RILEY BLACK

helicoptered over the region and took measurements with lidar, a method that bounces lasers between aircraft and the ground to precisely plot elevation. With this data, they ditched the plant cover digitally and mapped the hidden human-made structures.

The resulting paper, published in *Nature* in May, presented a tree-free view of the Casarabe world: a landscape peppered with urban centers featuring monuments, moats and causeways, and farmlands. Most surprising to the researchers was the density and connectedness of the sites, which were often within a two-hour's walk of another 10 settlements.

Study author Carla Jaimes Betancourt, an archaeologist and professor at Germany's University of Bonn, says the layout reflects Casarabe priorities: What "was necessary for them to live well" included urban amenities, greenspace and visiting friends and family nearby. "Maybe the archaeology [can] help us … remember … the important things in the world," says Betancourt.

—BRIDGET ALEX



DID THE MIGHTY *T. REX* stand alone, or were there three tyrannosaur species instead of one? The debate rages on.

FISH FOSSILS HELPED provide critical clues to determining the season when the dinosaurs were destroyed.

MELANIE DURING

SEASON OF DESTRUCTION

The Age of Dinosaurs ended on a spring day.

» **ON AN OTHERWISE** typical Cretaceous day 66 million years ago, a 7-mile-wide chunk of rock plowed into the Earth's crust and sparked a dinosaur-destroying mass extinction event. Paleontologists have now ascertained that this world-changing impact occurred during spring in the Northern Hemisphere.

The critical evidence comes not from dinosaurs, but from the relatives of today's sturgeon and paddlefish. Specimens found at the Tanis fossil site in North Dakota, including filter-feeding fish with impact debris stuck in their gills, are thought to have died minutes to hours after the collision. This connection prompted paleontologist Melanie During of Uppsala University in Sweden to take a closer look, inspiring a new approach for pinpointing the moment of impact.

"Fish like sturgeons and paddlefishes, although more diverse in the past than they are today, likely followed similar life-history patterns that we see in modern-day representatives," says Nicholls State University fish ecologist Solomon David, who was not involved in the study. By comparing growth patterns in fossil fish to those of their modern counterparts, During and colleagues set out to determine the season in which the Cretaceous fish died.

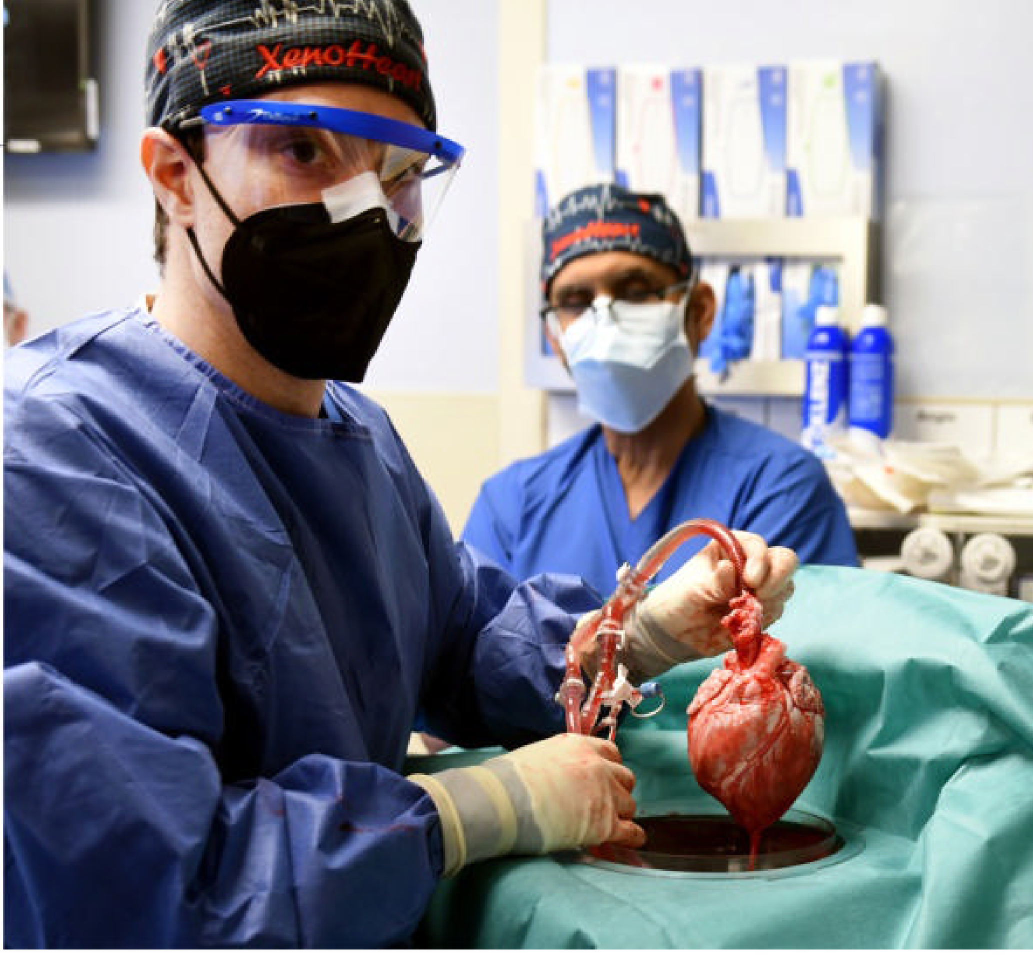
THE CRITICAL EVIDENCE COMES NOT FROM DINOSAURS, BUT FROM RELATIVES OF STURGEON AND PADDLEFISH.

The comparisons, reported in *Nature* last February, revealed that the fish at Tanis perished during spring. Given that many organisms court, mate and nest when the seasons start to warm, and are therefore more exposed than when hibernating or sheltering during colder seasons, the impact might have hit the Northern Hemisphere at a very vulnerable time. The implications for the Southern Hemisphere are as yet unclear.

"Future studies may want to look into the biological cycles of dinosaurs and their potential for sheltering and entering torpor," or hibernation, During says. Dinosaurs, pterosaurs and other organisms went extinct worldwide, but things may have played out differently at locations experiencing autumn. "I have already come across several studies that show that the biotic recovery in the Southern Hemisphere occurred over twice as fast as in the Northern Hemisphere," says During. If experts could find a site like Tanis elsewhere on Earth, it might shed more light on the pattern and timing of how the Age of Dinosaurs came to a close. —RILEY BLACK

PIG HEART TRANSPLANT OFFERS UNCERTAIN HOPE

The patient's survival breaks records, but his death raises crucial questions.



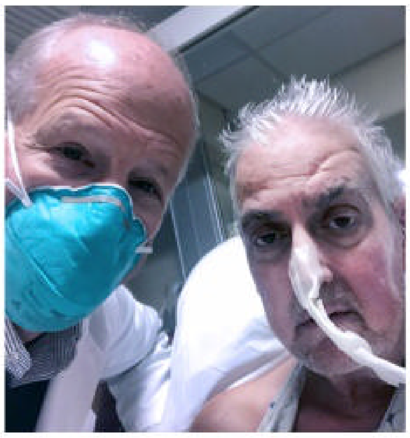
DESPERATELY ILL and seeking a miracle, David Bennett Sr. took a last-ditch gamble on Jan. 7, when he became the first human to be successfully transplanted with the heart of a pig. "It creates the pulse, it creates the pressure, it is his heart," declared Bartley Griffith, director of the surgical team that performed the operation at the University of Maryland Medical Center. "We are thrilled, but we don't know what tomorrow will bring us."

Bennett, 57, held on through 60 tomorrows, far longer than any previous patient who'd received a heart from another species. His remarkable run offered new hope that such procedures, known as xenotransplantation, could help relieve the perpetual shortage of donor organs, saving thousands of lives each year. (On average, 17 people die every day in the U.S. while waiting for a transplant.) First, though, experts will have to figure out what killed him.

THE EARLIEST ATTEMPTS at xenotransplantation of organs, involving kidneys from rabbits, goats, and other animals, occurred in the early 20th century, decades before the first successful human-to-human transplants. Rejection, which occurs when the recipient's immune system recognizes the donor organ as a foreign object and attacks it, followed within hours or days. Results improved after immunosuppressant drugs arrived in the 1960s, but most recipients still died after a few weeks. The record for a heart xenotransplant was set in 1983, when an infant named Baby Fae survived for 20 days with an organ from a baboon.

In recent years, however, advances in gene editing have opened a new possibility: modifying animals to provide user-friendly spare parts. Pigs could be ideal for this purpose, because they're easy to raise and reach adult human size in months. Although there's debate over the ethics of such organ farming, some biotech companies — including Revivicor, a subsidiary of Maryland-based United Therapeutics — are investing heavily in the prospect. So far, experimental transplants from pigs to baboons and pigs to brain-dead human patients have been promising.

The U.S. Food and Drug Administration granted "compassionate use" approval for Bennett's xenotransplant on New Year's Eve. The donor pig was bred by Revivicor from a line of animals in which 10 genes had been altered to improve the heart's immunocompatibility and keep it from growing too big. Beyond that, the pig was reared in isolation and tested regularly for viruses that could infect humans or damage the organ itself.



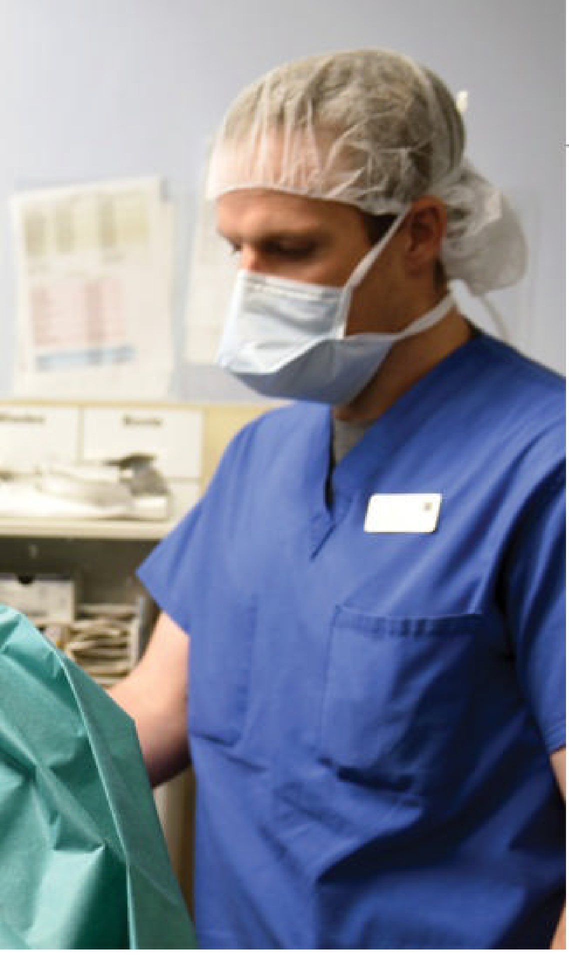
DAVID BENNETT (right) snaps a photo with Bartley Griffith, the director of the surgical team that performed the procedure.

BEFORE THE OPERATION, Bennett suffered from cardiac failure so severe that he'd been on a heart-lung machine for over a month. His new heart functioned "even better than a human transplant," says Muhammad Mohiuddin, scientific director of the University of Maryland's cardiac xenotransplantation program. Although he required two more surgeries in the first 12 days to treat a damaged artery and a bowel infection, Bennett was soon able to start physical therapy and spend time with his family.

On day 20, however, a worrisome sign appeared: Blood tests showed DNA fragments from porcine cytomegalovirus (PCMV), a microbe that can harm pig organ transplants, though it's not known to infect humans. The virus can remain latent in an animal's cells, undetectable by most screening methods until it begins replicating.

At that point, the levels of PCMV were too low to require urgent action. But 43 days after the procedure, Bennett was struck by an infection of the lungs and airway. Although different pathogens were likely responsible for this problem,

TOP AND BOTTOM: UNIVERSITY OF MARYLAND SCHOOL OF MEDICINE (2); MIDDLE: DAVID BENNETT JR.



MEMBERS OF THE surgical team at the University of Maryland Medical Center hold up the pig heart that was successfully transplanted into Bennett on Jan. 7.

EVERY 9 MINUTES, ANOTHER PERSON IN THE UNITED STATES IS ADDED TO THE NATIONAL TRANSPLANT WAITING LIST.

his PCMV counts were also rising. To fight off the invaders, the team administered a mix of antibodies known as intravenous immune globulin, or IVIG.

Bennett overcame the lung infection, but his health deteriorated suddenly on the 49th day, and an echocardiogram showed that his heart was failing. Then, biopsies revealed areas of dying tissue in that organ. Eleven days later, the team determined that the damage was irreversible and removed him from life support.

INITIALLY, GRIFFITH identified PCMV as the prime suspect in Bennett's demise. Further analysis, however, muddied the waters. Although the heart was swollen and stiff, no signs of active infection were evident. Nor were any of the classic markers of immune rejection.

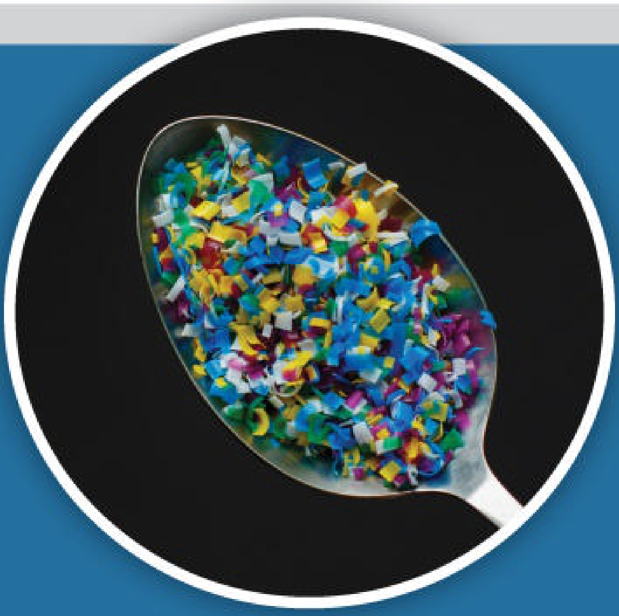
The University of Maryland team is investigating a range of potential culprits. Antibodies in the IVIG might have attacked the heart tissue. Some previously unknown form of rejection may have been at work. Or Bennett may simply have been too weak to withstand the stresses of the operation and its aftermath. "This individual was not in good physical shape going into transplant," says Jay Fishman, associate director of the transplantation center at Massachusetts General Hospital. It could take months to resolve the mystery. Meanwhile, researchers are working on improved screening methods for PCMV, and pondering new ways to control infection in xenotransplant patients. Still, experts regard Bennett's case as a major step toward a future in which replacement organs are available on demand. "There's a lot of learning that needs to be done," says Mohiuddin. "But we have come a long way from the point where this looked impossible."

Adds Griffith: "If you're a scientist, you've got to say, 'This is real.' "

— KENNETH MILLER

TAKING MICROPLASTICS TO HEART — AND LUNGS

THE WORRISOME PARTICLES TURN UP DEEP IN THE HUMAN BODY.



UKROLENOCHKA/SHUTTERSTOCK

In recent years, scientists have found plastic pollution in Earth's most remote places — from the top of Mount Everest to the bottom of the deepest ocean trench. But two studies released in 2022 brought the problem much closer to home.

In May, researchers in the Netherlands revealed the presence of tiny particles known as microplastics in the human bloodstream. Using a technique involving gas chromatography-mass spectrometry, which converts materials to gas and measures the mass and charge of their ions, the team examined the blood of 22 donors. In their study, published in the journal *Environment International*, they found microplastics in samples from roughly three-quarters of the subjects. Concentrations averaged 1.6 micrograms per milliliter, or about a teaspoon of plastic for every 264 gallons of fluid.

"We have now proven that our bloodstream, our river of life as it were, has plastic in it," declared lead author Heather Leslie, an environmental scientist at the Free University of Amsterdam, in the accompanying press release.

Soon after, in the journal *Science of the Total Environment,* researchers at England's University of Hull reported finding microplastics in living human lungs for the first time. Analyzing tissue removed during surgical procedures, the team detected the particles in 11 out of 13 samples.

What surprised the scientists was not only the near-ubiquity of the specks, but also how deeply they had spread: There were significantly more in the lower portion of the lung, where the airways are narrowest. "We thought particles of this size would have been trapped by mucus before making it that deep," says Laura Sadofsky, a senior lecturer in respiratory medicine and the study's senior author.

Microplastics, which result from the breakdown of items ranging from water bottles to machine parts, can be absorbed through ingestion or inhalation. They've been shown to cause health problems in many animals, including aneurysms in fish and cognitive impairment in hermit crabs, and to have toxic effects on cells in vitro. Their impact on human health, however, is not yet known.

"That's really where we need to go next," Sadofsky says. But the particles' omnipresence makes them challenging to study outside of a sealed lab. "They're in the air around us," she explains. "You have to be very careful that what you're finding isn't just coming from there."

— KENNETH MILLER

WHILE RECTAL cancer is rarely fatal, conventional treatments can cause permanent damage.

DOUBLE-PLAY AGAINST CANCER

A PAIR OF NEW APPROACHES ACHIEVES UNPRECEDENTED RESULTS.

CANCER RESEARCHERS don't toss around superlatives lightly. In June, however, experts used the term *unheard of* to describe the results of two different clinical trials.

Both studies were reported at the annual meeting of the American Society of Clinical Oncology (ASCO). The first involved rectal cancer, a disease that is seldom fatal if caught in time, but whose treatment often leads to permanent bowel, urinary and sexual dysfunction. At Memorial Sloan Kettering Cancer Center, researchers tried a gentler approach: Instead of chemotherapy, radiation and surgery, they used dostarlimab — a type of drug known as a checkpoint inhibitor, which enhances the immune system's ability to target and destroy cancer cells.

The 18 participants in the trial were chosen because their tumors shared a genetic defect that prevents cells from repairing damage to DNA. To the researchers' amazement, the cancer vanished in every single patient — with no major side effects and no need for further treatment. "I believe this is the first time this has happened in the history of cancer," the trial's senior author, oncologist Luis Diaz Jr., told *The New York Times*. Added lead author Andrea Cercek: "There were a lot of happy tears."

Despite the study's small size, it points towards a bright future for checkpoint inhibitors. Since their introduction a decade ago, these medications have become the treatment of choice for a growing array of cancers — particularly varieties with multiple mutations, like those in the trial, which can be easier for the immune system to detect. And the drugs' efficacy isn't their only potential advantage. "These patients might have been cured with standard therapy, but with checkpoint inhibitors they won't suffer the consequences of those treatments," says Alan Venook, a colorectal cancer specialist at the University of California, San Francisco. "The quality-of-life implications are dramatic."

THE SECOND SET of headline-grabbing results concerned breast cancer and a protein known as HER2. Medications that block HER2, introduced in the 1990s, have proved remarkably effective against cancers that express high levels of the protein. These HER2-positive breast cancers, however, account for only 15 to 20 percent of cases. Conventional HER2 blockers don't work against cancers that express lower levels of HER2, which represent about 50 percent of breast cancer cases. But in a study published in June in the *New England Journal of Medicine*, a drug that targets HER2 in a novel way showed unprecedented promise.

In the trial, led by Sloan Kettering oncologist Shanu Modi, 557 women with HER2-low metastatic breast cancer were divided into two groups: One cohort took a medication called trastuzumab deruxtecan, approved in 2019 for HER2-positive breast cancers. The other underwent standard chemotherapy. Patients in the trastuzumab

RYANKING999/ISTOCK VIE GETTY IMAGES

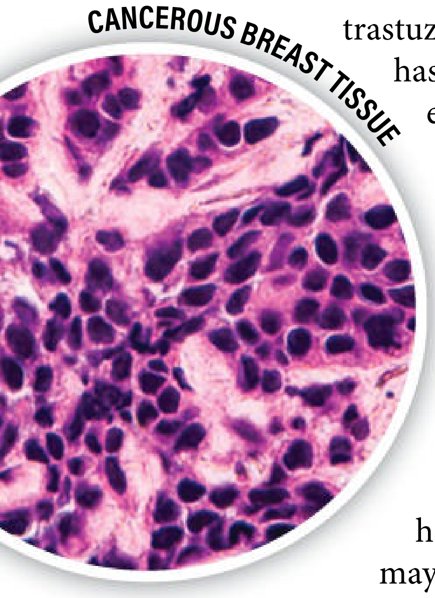
→ 2022 IN BRIEF

3D-Printed Ears

In a clinical trial, doctors implanted a 3D-printed ear onto a 20-year-old patient in March. It's the first-ever 3D-printed body part to be made from the patient's own cells. Doctors hope that it will continue to gain natural appearance and function with time, as the new ear regenerates cartilage tissue.

deruxtecan group survived for a median of 23.4 months, versus 16.8 months for the control group. Although that difference might seem modest, it's far beyond the norm in drug trials for metastatic breast cancer, where improvements are typically measured in weeks at best. When Modi and her co-authors finished their presentation at the ASCO conference, they received a standing ovation.

Trastuzumab deruxtecan belongs to an emerging category of cancer treatments known as antibody drug conjugates (ADCs). These medications use an antibody to deliver a chemotherapy drug to tumor cells (like those below) that carry a specific protein — in this case, HER2. When the antibody locates such a cell, it binds to it and releases the chemo, which kills not only that cell but its neighbors. Instead of carpet-bombing the body, as with conventional chemo, ADCs behave like guided missiles, focusing greater firepower on the tumor and reducing collateral damage to normal tissues.



Like most chemotherapies, trastuzumab deruxtecan has harsh side effects, including nausea, vomiting and blood disorders; it can also cause lung damage, which killed three trial participants. For patients with advanced cancers, however, these risks may be acceptable for a few more months of life. The study convinced clinicians and regulators, as well: In August, the U.S. Food and Drug Administration expanded its approval of trastuzumab deruxtecan to cover inoperable or metastatic HER2-low breast cancer.

"To see the benefit of HER2-directed treatment extended to a much larger group of patients is very impressive," says Halle Moore, director of breast medical oncology at the Cleveland Clinic, who enrolled some patients in the trial. "These results were really practice changing." —KENNETH MILLER

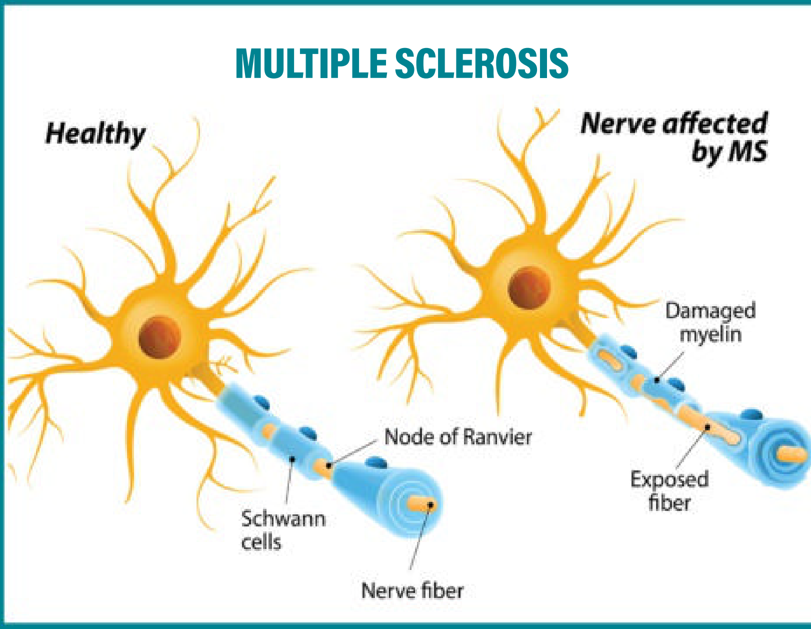
FROM LEFT: DAVID A LITMAN/SHUTTERSTOCK; DESIGNUA/SHUTTERSTOCK

THE MICROBE BEHIND MULTIPLE SCLEROSIS?

NEW EVIDENCE SUGGESTS A COMMON VIRUS PLAYS A CENTRAL ROLE.

Scientists have spent decades searching for the underlying cause of multiple sclerosis (MS), a neurological disease that afflicts nearly a million Americans. The highly infectious and exceedingly common Epstein-Barr virus (EBV) has long been a prime suspect, but firm evidence has been lacking — until now. In January, a team led by Alberto Ascherio, an epidemiologist at the Harvard T.H. Chan School of Public Health, released the first study showing strong evidence that EBV plays a key role in most cases of MS.

The paper, published in the journal *Science*, grew out of a 20-year collaboration with the Department of Defense Serum Repository, which stores leftover vials from the blood tests taken by active-duty military personnel as part of regular medical screenings. Testing samples collected from over 10 million service members between 1993 and 2013, Ascherio and his colleagues checked whether each individual was infected with EBV at the time their sample was taken. They then compared samples from 801 service members who developed MS afterwards with samples from over 1,500 service members who didn't develop the disease, which occurs when the immune system attacks the insulation surrounding nerve cells in the brain and spinal cord.



Out of the MS patients, the team found only one whose serum tested negative for EBV before they were diagnosed. The researchers concluded that people with EBV were a whopping 32 times as likely to develop MS as those without the virus.

The team also measured the samples for neurofilament light chain, a biomarker of nerve degeneration that increases in people with MS. They found that levels rose only after EBV infection. And they found no connection between MS and any other virus. "We looked for antibodies to 200 different viruses," explains Harvard University epidemiologist Kassandra Munger, a co-author of the study, "and antibodies to Epstein-Barr proteins were far and away the highest difference between the cases and controls."

At present, there's no cure for MS, though medication can slow its progression in some people. The study's findings could eventually help ensure that fewer people develop the potentially debilitating disease, which can affect patients' mobility, speech, thinking and vision. Although other factors have also been shown to increase risk — like certain gene variants, cigarette smoking, obesity and low levels of vitamin D — none come close to the association the researchers found with EBV. "This is the most compelling evidence to date," Munger says, "that EBV is the leading causal factor in multiple sclerosis."

In their report, the team stressed that EBV alone is not enough to trigger MS; over 90 percent of humans get the virus, which sometimes causes mononucleosis, by early adulthood. Nonetheless, Ascherio noted in a news release the day the study was published, "this is a big step, because it suggests most MS cases could be prevented by stopping EBV infection." That's a tall order, but there's reason for optimism: Clinical trials of two vaccine candidates were launched in January and May, and more are in the pipeline. —KENNETH MILLER

RETRONS GIVE GENE EDITING A BOOST

A NEW TECHNIQUE ENABLES SCIENTISTS TO EDIT GENES INSIDE HUMAN CELLS.

A new gene-editing tool could help solve a perennial challenge for scientists striving to alter genes in human cells: getting that modified DNA inside the cell in the first place.

The approach uses segments of DNA found in certain bacteria called retrons. These little genetic factories can manufacture DNA within the cell itself. In a study published in February in *The CRISPR Journal*, scientists say they've used retrons, paired with the gene-editing system CRISPR-Cas9, to make edits in human cells. The work follows a study published in December 2021 that also used retrons — and demonstrated their use in human cells for the first time.

The new bacterial tool could lead to genetic edits that are more precise and easier to make, says Bin Zhao, a molecular biologist and a co-author on the 2022 paper. Today, most gene-editing technologies based on the CRISPR system require scientists to cut apart the double-stranded DNA helix and remove a snippet of DNA from the cell's genome. Then they provide the cell with new genetic material called a template — manufactured in the lab and containing their desired edit — for the cell to use as it repairs the break. Those templates are delivered to the cell from the outside, and if not enough make it, the intended edit might not be successful.

By contrast, retrons can churn out hundreds of copies of short stretches of DNA inside the cell, far more than scientists would ever insert by themselves. "The chance of inserting what you want goes up quite drastically," says Ilya Finkelstein, a molecular biologist at the University of Texas at Austin. Retrons might also enable gene edits that are far larger than is currently possible: Current systems allow edits of up to 40 base pairs of DNA, whereas retrons might be able to edit up to 1,000 base pairs, or even more.

THE NEW BACTERIAL TOOL COULD LEAD TO GENETIC EDITS THAT ARE MORE PRECISE AND EASIER TO MAKE.

Finkelstein compares the field of retron gene-editing right now to the early days of CRISPR. In the 10 years since, CRISPR has enabled new treatments for sickle cell anemia, heart disease and cancer, as well as the promise of gene-edited crops and bioengineered bacteria. Retrons carry that same potential for innovation. "We don't know what the next breakthrough will bring," says Finkelstein. — NATHANIEL SCHARPING

U.S. RULING UPENDS REPRODUCTIVE HEALTH CARE

A landmark Supreme Court decision ends nearly 50 years of constitutional abortion rights.

THE WRITING WAS on the wall by May, when a source leaked a U.S. Supreme Court draft opinion striking down Roe v. Wade — the nearly five-decade-old ruling that secured the right to legal abortions around the country. In a 5-4 June decision, the Court made good on its telegraphed intent and overturned Roe. The ruling leaves abortion laws up to each U.S. state. That triggered full bans in at least 10 states this summer, including Louisiana, South Dakota, Kentucky and Texas, with many others passing or pursuing tight abortion restrictions.

As the decision came down in late June, women and pregnant people scrambled to figure out how it would affect their lives. Several months later, many clinics are still grappling with a wave of disruption in reproductive health care, while patients face a growing list of health impacts.

In states where abortion has been outlawed or severely restricted, pregnant people have limited options when a pregnancy endangers their well-being, says Howard Forman, a public health professor and emergency room radiologist at Yale University. When patients show up with life-threatening pregnancies, such as those that cause dangerously high blood pressure, doctors might face the decision of whether to perform a banned abortion — or watch and wait as patients get sicker or die.

"Patients may find it more challenging to receive care," Forman says. "Delayed care can put them at risk of loss of life, loss of fertility or other harms."

Specifically, adequate treatment has become elusive for some people who are miscarrying or experiencing uterine bleeding during a pregnancy. Treatment for these conditions can involve removing the uterine lining, the same dilation and curettage procedure used to perform many abortions. This overlap has prompted fears of criminal liability in some providers, as well as reluctance to provide particular care. One prominent example was 42-year-old Texan Marlena Stell, who was denied care — in 2021 after a Texas "heartbeat bill" restricted abortion — and had to carry a dead fetus for two weeks.

The Dobbs ruling that overturned Roe v. Wade has also delivered some immediate impacts to the chronic illness community. In Texas and Virginia, people with lupus and rheumatoid arthritis have been denied prescriptions for methotrexate, an immune-suppressant drug that is sometimes used to induce abortion.

THE COURT'S decision has already set off a domino effect of further long-term health consequences. The past decade-plus of prior research on the impacts of being denied an abortion shows how those dominoes might fall.

In a first-of-its-kind investigation that began in 2008, known

AS OF NOVEMBER, 13 U.S. states had nearly full bans on abortion in effect, while others awaited court decisions.

TOMMYSTOCKPROJECT/SHUTTERSTOCK

as The Turnaway Study, researchers at the University of California, San Francisco, studied nearly 1,000 women for about five years, looking at how people who sought and received abortions fared compared to those denied access.

Those turned away when seeking abortions were more likely to suffer serious health issues such as eclampsia — sky-high blood pressure that can lead to seizures — and severe postpartum bleeding; those complications put survey participants at higher risk of death over the study period. Plus, for at least five years after pregnancy, they had more long-term chronic health issues like migraines and joint pain. They also suffered higher rates of household poverty, an effect that lasted for four years or more, and their children struggled more developmentally.

Today, multiple studies have documented how the most vulnerable populations in the U.S. will bear the brunt of the Dobbs decision's health consequences. "Communities with impoverished, unmarried women of color will be the most impacted," says Kecia Gaither, director of maternal-fetal medicine at New York City Health + Hospitals/Lincoln. Black women already face higher rates of pregnancy complications than white women — for example, more than 12 percent of U.S.-born Black women develop preeclampsia, compared to only 7 percent of white women. Alarmingly, they are also three to four times more likely to die from pregnancy, largely due to unequal access to medical services and pregnancy care that may not be responsive to their needs.

In a post-Dobbs world, that population may be in even greater danger. Researchers from Emory University and the University of Alabama reported in 2021 that after some states limited abortion access, Black patients showed a greater jump in preterm birth rates than non-Black patients. The team will continue to study how restricting abortion rights affects underserved populations.

SUPPORTERS OF abortion rights have begun mobilizing to help pregnant people in affected states access the procedure. Despite state bans on abortion pills, some health workers are advising people on how to obtain the medication through cross-border telehealth consults. Other providers are gearing up to shift full abortion services to new locations, including a proposed floating clinic in the Gulf of Mexico. "We can be opening up clinical sites in states not subject to the trigger laws," says Monica McLemore, a nurse practitioner and professor at UCSF and the University of Washington. "This is an all-hands-on-deck situation."

BLACK WOMEN ARE ALREADY THREE TO FOUR TIMES MORE LIKELY TO DIE FROM PREGNANCY.

As of July, President Joe Biden issued an executive order that offers legal support for out-of-state abortion services, which could help smooth the road ahead for pregnant people seeking to access such care. But in general, the uncertainty of that road presents a challenge, McLemore notes. Since Congress could still pass future laws that guarantee nationwide abortion rights, it's tough to gauge just how many people's health will be impacted — and how long those impacts will endure. — ELIZABETH SVOBODA

DEPRESSION IS A MYSTERIOUS AND DEVASTATING ILLNESS. RESEARCHERS ARE CLOSER THAN EVER TO FIGURING OUT ITS SOURCE.

PONOMARIOVA_MARIA/ISTOCK VIA GETTY IMAGES

THE HUNT FOR A CAUSE

IF YOU'VE FOUND yourself struggling with persistent melancholy or malaise in recent years, you're not alone: Twenty-one million adults in the U.S. — or 8 percent of the population — had at least one major depressive episode in 2020. That prevalence is even higher, 17 percent of the population, among 18- to 25-year-olds.

With so many people affected, it's surprising how little we know about depression in the brain and body.

The neurotransmitter serotonin has long been a prime suspect for the condition's cause. That's largely based on the notion that selective serotonin reuptake inhibitor drugs (SSRIs), which increase serotonin levels in the brain, seem to alleviate depression symptoms for many people. But this July, a team led by researchers at University College London did a systematic review of 17 recent studies that looked for a link between serotonin and depression. They didn't find one.

Back to square one? Not exactly. In June, a team of Japanese researchers reported a significant correlation between depression and a person's ratio of two types of white blood cells — neutrophils and lymphocytes — but the relationship was only notable in males. This ratio is an indication of inflammation in the body, which can build up as a result of chronic or long-term stress. A few months earlier, in April, an Australian team reported results from a genome-wide association study that searched over 300,000 genomes for links between genetic biomarkers and 10 different psychiatric disorders. For major depressive disorder, a few stood

NEARLY 1 IN 10 OF ALL U.S. ADULTS HAD AT LEAST ONE MAJOR DEPRESSIVE EPISODE IN 2020.

out, including neutrophil count, lymphocyte count and C-reactive protein level, a compound produced by your liver when the body's inflammation levels are high.

The connection between depression, inflammation and stress has been coming to fruition for years now, mostly thanks to stronger and stronger correlative studies. But researchers in Canada may have finally found an actual causal link, published in January in *Nature Communications*. To find it, they looked to the blood-brain barrier, the border between the cardiovascular system and the nervous system. There, specialized cells regulate what can and can't travel from blood vessels to the brain, letting essential oxygen and nutrients through while protecting from hazards like pathogens and toxins. "I call it the ultimate frontier," says senior author Caroline Menard, a neuroscientist at Laval University and the CERVO Brain Research Centre in Québec.

Menard's team triggered depressive-like symptoms in female mice by exposing them to stress in the lab. When they looked in these mice's brains, they found leakiness in the blood-brain barrier in regions related to mood. The team then identified a way to dial up this leakiness, which also triggered the symptoms (and allowed symptoms to resolve when dialed back down). The stressed and "depressed" mice also had elevated levels of a compound called soluble E-selectin in their blood. Notably, the researchers found the same compound in the blood of humans with depression — as well as leaky blood-brain barriers in the post-mortem brains of women diagnosed with major depressive disorder.

CHRONIC STRESS is already a known risk factor for depression. But the pathway by which long-term stress can lead to inflammation, which in turn weakens the blood-brain barrier protecting the mood-controlling areas of the brain, is new. The development could lead to new treatments and preventions that exceed the effectiveness of methods like SSRIs.

Still, don't throw out your SSRIs just yet — more research is definitely needed to understand why they work for so many people, whether it's via serotonin levels in the brain or not. Menard's research may bring us one step closer to figuring it out. "The brain is really good at repairing itself; it's just that if you don't give it the chance, by being stressed all the time, then it's not going to work," she says. "It's not irreversible, but you need to work on it." And, critically, Menard adds: "It's important to seek help if needed." —ANNA FUNK

FROM TOP: PETERSCHREIBER.MEDIA/SHUTTERSTOCK; GORODENKOFF/SHUTTERSTOCK

Inflammation Overload

Inflammation happens when your body is fighting — or thinks it's fighting — intruders. Essentially, it's your immune system springing into action and bombarding its target with white blood cells, cytokines and other cells. A natural part of the healing process, acute inflammation is what gives you a fever when you have the flu, or makes the area around a healing cut redden and warm. Chronic inflammation, on the other hand, happens when your body doesn't turn off the inflammatory response. This can happen for a variety of reasons, including chronic stress: Stress triggers an inflammatory response, so if you never de-stress, your body never gets a break from the inflammation. It's the main reason chronic stress can make you physically ill, and it's associated with conditions like rheumatoid arthritis, heart disease, asthma, Alzheimer's disease and more. —A.F.

OVER TIME, CHRONIC INFLAMMATION CAN DAMAGE YOUR DNA, INCREASING THE RISK OF CANCER.

Coaches 4 Trans Inclusion
Protect Trans Youth!
#LetKidsPlay

LGBTQ ADVOCATES gathered at the Minnesota State Capitol in March to push back against proposed legislation targeting trans youth.

GENDER-AFFIRMING CARE TIED TO IMPROVED MENTAL HEALTH

Transgender health care is a hot-button topic, but the science on its benefits for trans youth is clear.

THIS YEAR, a historic wave of legislation targeting transgender rights has continued. By November, 17 U.S. states had proposed more than 30 bills that aim to restrict access to puberty blockers and hormone injections for minors.

In Alabama, for example, a bill passed this April making it a felony to provide gender-affirming care to transgender minors. If all the other proposed bills are enacted, over 58,000 trans kids and young adults who live in these states would lose access to these medical treatments, according to the Williams Institute at the University of California, Los Angeles. But these measures are facing a growing body of peer-reviewed data on the benefits of gender-affirming care — meaning treatments that help a transgender or nonbinary person match their outward traits with their gender identity.

"It's very important to point out that this legislation is based on a gross misrepresentation of scientific evidence," says Diana Tordoff, an epidemiologist at the University of Washington.

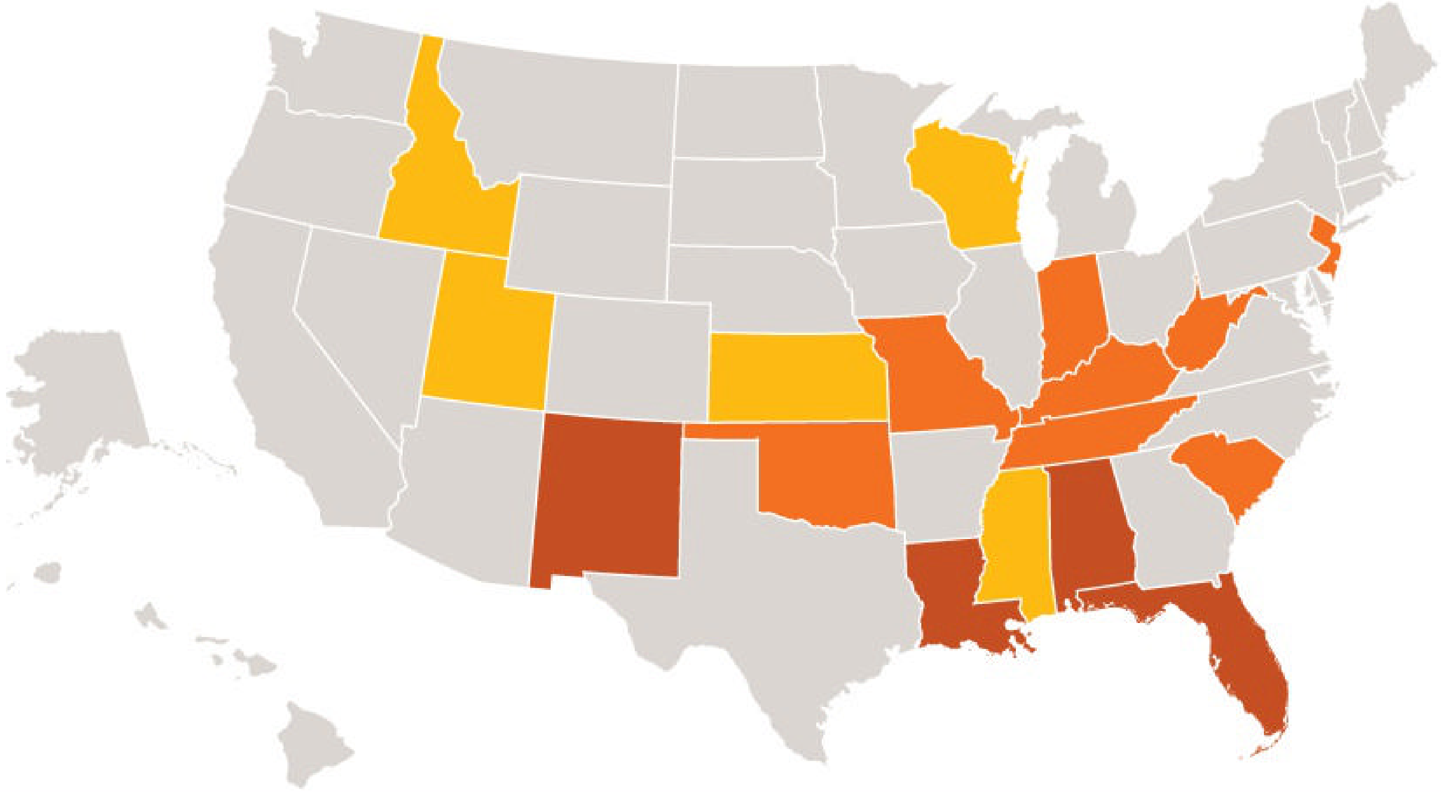
In late 2021 and early 2022, several studies dug deep into the mental health benefits of gender-affirming care — and found that these treatments greatly reduce depression and suicidal thoughts in trans teens and young adults. It's well known that this population is particularly vulnerable to mental health issues. In fact, LGBTQ youth are more than four times as likely as their peers to attempt suicide, and trans and nonbinary youth are the most vulnerable within this community, according to a national survey of nearly 34,000 LGBTQ youth by the nonprofit Trevor Project. That's why medical professionals and scientists have argued that supporting such care would be lifesaving, benefitting the health and wellbeing of thousands of trans youth.

YOU'VE LIKELY heard of puberty blockers. This form of gender-affirming care pauses certain physiological changes in a child or teen — administered alongside other measures, like talk therapy — to give a young person time to navigate their gender identity. At 14 years old, that person can start hormone replacement therapy via injections of testosterone or estrogen, according to the World Professional Association for Transgender Health. (This will make their physical attributes look more feminine or masculine.) Later, in their teenage years, they may also consider surgical treatments, like genital or "bottom" surgery, to create a penis or a vagina. A long list of medical organizations supports this care, including the American Academy of Pediatrics, the American Psychological Association and the American Medical Association.

"Every major medical association in the United States recognizes the medical necessity of transition-related care for improving the physical and mental health of transgender people," the AMA wrote in 2021 in a letter to the National Governors Association.

To date, over a dozen studies have found that access to gender-affirming care is tied to better mental health outcomes in trans youth. For example, a study conducted by the Seattle Children's

LEFT: MICHAEL SILUK/ALAMY STOCK PHOTO



ANTI-TRANS HEALTH CARE BILLS BY STATE

In 2022, these 17 states all proposed legislation to restrict access to gender-affirming care for transgender minors.

🟥 Bill(s) passed into law

🟧 Bill(s) pending

🟨 Bill(s) didn't advance

Source: LegiScan API

Gender Clinic and published in *JAMA Network Open* in February revealed that access to gender-affirming care led to 60 percent lower odds of depression and 73 percent lower odds of suicidal thoughts and actions over one year of follow-up, compared to trans teens and young adults who didn't get care.

Another study, by researchers at Stanford University School of Medicine and the Fenway Institute, a Boston-based LGBTQ health care and research organization, analyzed survey data from 27,715 trans adults and published similar findings in *PLOS One* in January. The scientists also found that individuals who received hormones during adolescence were significantly less likely to have considered suicide over the past year than those who didn't get care until adulthood.

Likewise, researchers from the Trevor Project discovered that access to hormone treatment was associated with lower odds of recent depression and suicide risk in trans youth, compared to those who wanted hormones but did not receive them. In their data analysis, published in 2021 in the *Journal of Adolescent Health*, the scientists also controlled for factors that may contribute to improved mental health, like a parent's acceptance of their child's gender identity.

For trans youth — and their parents, who are often trying to support their kids and navigate the health care system — access to care is essential, says researcher J. Nyla McNeil. "Trans people, and trans youth especially, are the only people who should be making decisions about their own body," adds McNeil, who works with the Trans CARE Collaborative at the University of Wisconsin, Madison. "[We must] listen to the people who need the care."

DESPITE THESE findings, policymakers across the country are trying to pass bills that misrepresent scientific evidence to restrict access to gender-affirming care.

TO DATE, OVER A DOZEN STUDIES HAVE FOUND THAT GENDER-AFFIRMING CARE IS TIED TO BETTER MENTAL HEALTH IN TRANS YOUTH.

Take puberty blockers, which have been used for decades; it's well known that they are medically safe, and their effects reversible. Yet anti-trans legislation commonly claims this medication will cause permanent alterations to kids' bodies. Additionally, many bills paint the picture that hormones are provided to any trans youth who asks for them. In fact, current guidelines state hormones cannot be provided before the onset of puberty, and they are typically given to teens who have shown persistent, well-documented distress about the mismatch between their biological sex and their gender identity.

This rhetoric has allowed the Texas child welfare agency, for example, to investigate whether parents providing gender-affirming care to trans youth are committing child abuse. This July, a Travis County judge in Texas temporarily halted two investigations, but at least seven cases against parents of trans kids remain open.

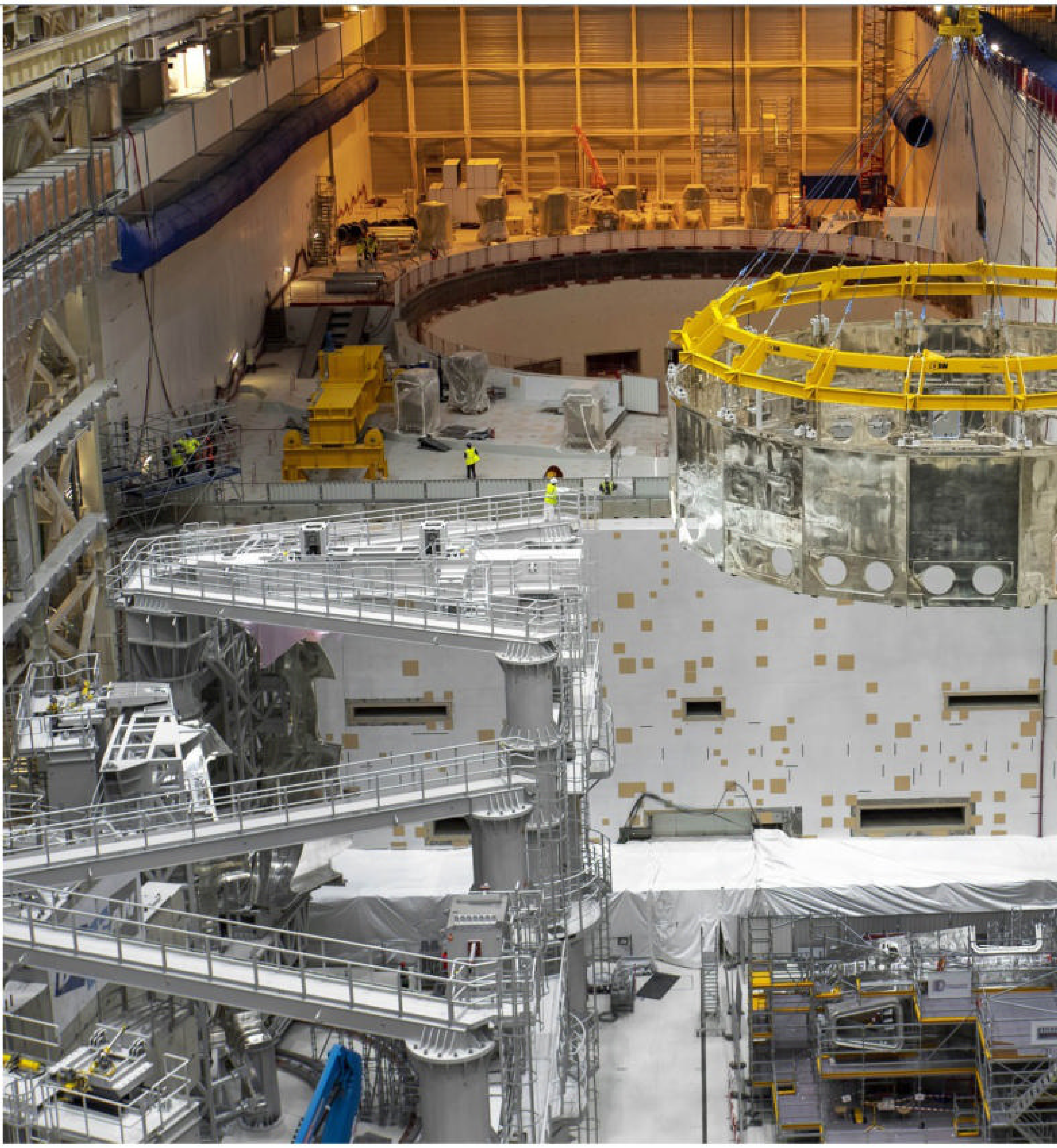
Although many anti-trans bills are being introduced, Tordoff notes that many of them have been shot down and not signed into law — thanks, in part, to quality research and consistent data being published on gender-affirming care.

Beyond datapoints and graphs, Green says the presence of allies who are advocating for trans support and healthcare can notably improve the wellbeing of trans youth. "I am concerned about the messages that young queer and trans folks are receiving in the media about their rights," Green says. "Trans and nonbinary young people are not in this alone." —HELEN SANTORO

FROM TOP: KELLIE JAEGER/DISCOVER; SEVENTYFOUR/ISTOCK VIA GETTY IMAGES

FUSION'S FUTURE

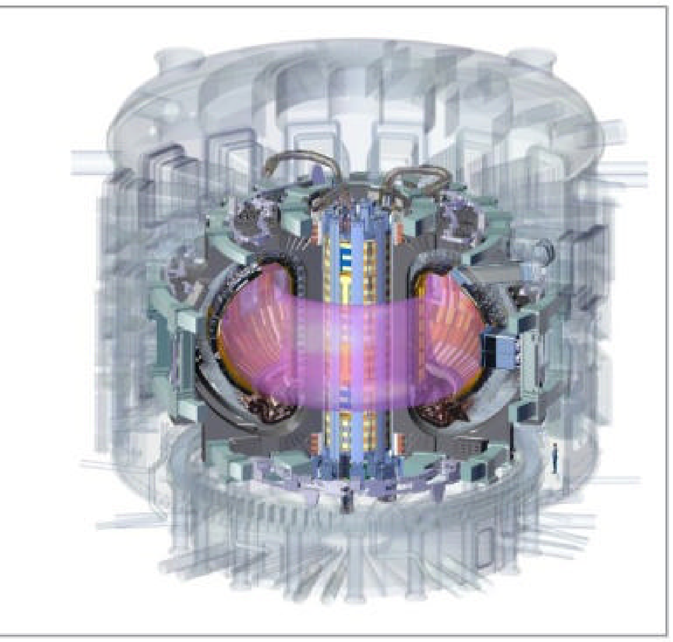
For decades, fusion energy has been a dream. This year, it came closer to reality than ever.



» THE WORLD'S LARGEST nuclear fusion device, which is currently being built in France by a collaboration of 35 nations including the U.S., is expected to be completed by 2025. Known as ITER (International Thermonuclear Experimental Reactor), the experimental device is poised to demonstrate that fusion energy can be a viable energy source. New advances in fusion technology have dramatically increased its chances of success.

With nuclear fission, an atom is split in two, creating enormous energy. Fission powers today's nuclear power plants (as well as atomic weapons). Fusion takes the opposite approach, fusing two atoms together, rather than ripping them apart.

Fusion is different from fission in other ways, as well. Fusion is relatively safe: It produces far less radioactivity and hazardous waste than fission. It doesn't risk out-of-control chain reactions and meltdowns. And it creates more energy than fission, without producing greenhouse gases. In short, fusion sounds like the perfect replacement for fossil fuels, and it would be — if it could be made to work.



The problem is not the science. "We understand the physics pretty well; we can make fusion," says Livia Casali, a nuclear physicist at the University of Tennessee, Knoxville, and an ITER Fellow. The obstacles that remain are engineering challenges.

Creating fusion energy means making — and controlling and containing — something very like a small star. (After all, our sun is essentially a giant fusion reactor.) To achieve this, ITER is the most complex engineering project ever built, Casali says. And results from labs around the world are beginning to confirm this audacious pursuit might actually be possible.

IN APRIL, THE WHITE HOUSE ANNOUNCED INITIATIVES TO ACCELERATE THE DEVELOPMENT OF FUSION ENERGY.

A team at the National Ignition Facility in Livermore, California, reported in January 2022 that, for the first time, they achieved a burning plasma condition — the state when the fusion reaction gets most of its energy from the nuclear reaction itself rather than from outside energy sources. Meanwhile, in the U.K., scientists at the Joint European Torus (JET) laboratory created 59 megajoules of sustained fusion energy, setting a new world record. In a press release announcing the achievement, project leaders of ITER described the JET results as a strong indication that they

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IN 2021, ITER's thermal shield was installed around the tokamak reactor (illustrated below), which harnesses the energy produced by fusion.

IMAGEFLOW/SHUTTERSTOCK

were on the right track to demonstrating full fusion power.

In April, the White House announced a set of initiatives intended to accelerate the development of fusion energy. "The goal has changed," says Steven Cowley, director of the Princeton Plasma Physics Laboratory. The U.S. government has gone from "Let's look at the science of this" to "Let's make some electricity," Cowley says.

Making fusion a practical and cost-effective source of energy will require continued improvements and innovation. But these recent advances suggest that, far from being a quixotic project, a world powered by fusion energy is a realistic goal. And it is an urgent one, says Casali. "If we want to act on climate change, we don't have much time to wait. Fusion is the winning card that we must play." — AVERY HURT

LARGE LANGUAGE MODELS: A STEP CLOSER TO GENERAL AI

IT STARTS WITH A SIMPLE GAME: GUESS THE MISSING WORD. PRETTY SOON, COMPUTER PROGRAMS ARE WRITING AD COPY, TRANSLATING TEXTS AND EVEN WRITING CODE. BUT THAT DOESN'T MAKE THEM SENTIENT (YET).

» **Large language** models (LLMs) are deep-learning algorithms that can "understand" and produce text, or as you and I might put it, read and write. Based on neural networks loosely modeled on the human brain and trained on enormous amounts of data, these forms of artificial intelligence are language-prediction machines. When given a few starting words, they supply the word or phrase that is statistically most likely to occur next in the sentence. After playing "guess the missing word" repeatedly, they learn the patterns of human language — and a lot more, it seems.

You've already engaged with a similar program if you've used a text app with an auto-complete feature. But Brian Christian, a researcher, programmer and author of several books about AI, describes LLMs as "auto-complete on steroids."

Indeed, the talents of LLMs far exceed suggesting a missing word. They can read a book and summarize the plot, compose ad copy, and explain a joke. LLMs have even taught themselves to write software code.

This facility with language has led some people to believe that LLMs are getting close to general AI — that is, AI that can learn pretty much anything a human can, as opposed to narrow AI, which can learn only a particular set of tasks. In a paper published May 2022 in *Daedalus*, Blaise Agüera y Arcas, a machine-intelligence expert at Google, wrote that he thinks LLMs may be the foundation for general AI, and eventually may achieve consciousness.

Blake Lemoine thinks they already have. Lemoine, a computer scientist formerly at Google, incurred the wrath of the company and made headlines when his conversations with LaMDA, an LLM designed by Google, led him to conclude that the system was sentient. It's not hard to see how one might wonder if there's more going on here than muscular auto-complete. People who've interacted with these programs tend to use words like *uncanny* and *mind-blowing* to describe the experience. Still, the consensus of other experts seems to be that Lemoine has been duped by some very cleverly designed software. Agüera y Arcas made it clear that he does not think LaMDA is sentient — yet.

John Laird has been working toward general AI for much of his career. Now the John L. Tishman Emeritus Professor of Engineering at the University of Michigan, Laird is continuing his research at the Center for Integrated Cognition in Ann Arbor. "It's a really exciting time because of these advances," he says, but adds that, in his opinion, general AI is still many years away.

Christian agrees that LLMs aren't there yet. But he still thinks these programs are an important step toward general AI. "Language captures a great deal of the many things human minds do," he says. "I wouldn't be surprised if developments in language processing are among the elements that lead us to an artificial system capable of quite general processing." — AVERY HURT

AI IN MEDICINE
Scan the code with your phone for more: AI and disease diagnostics.

U.S. PASSES HISTORIC CLIMATE ACT

CONGRESS APPROVES NEARLY **$370 BILLION** IN EMISSIONS-REDUCTION AND CLEAN ENERGY STRATEGIES.

FOR MORE than half of 2022, prospects for U.S. action to tame the climate crisis seemed grim. Even as intense heat waves, deadly floods and rampaging wildfires were highlighting yet again the costs of climate inaction, legislative efforts in Congress seemed dead by midsummer.

Then, whiplash.

In August, President Joe Biden signed the Inflation Reduction Act, or IRA. The name belied its history-making significance: $369 billion committed to slashing greenhouse gas emissions and enhancing energy security. Notably, it's the first major U.S. environmental law since sweeping amendments to the Clean Air Act in 1990. It's also the first major U.S. law ever to focus on climate change. Most importantly, analyses by three independent research groups projected the IRA could cut U.S. planet-warming emissions by about 40 percent below 2005 levels.

"We finally have it," says Anand Gopal, executive director of policy research with Energy Innovation, a think tank that produced one of the analyses. "I'm over the moon."

PRESIDENT BIDEN signs the Inflation Reduction Act in the White House Aug. 16, alongside Democrat leaders in Congress.

To reach their conclusions, Gopal and his colleagues used a model that simulates the impact of energy policies. Similar conclusions from the two other research teams adds confidence in the projections, which show much-needed acceleration in a positive 15-year trend: U.S. emissions have been dipping since 2007. But the pace has not been fast enough to meet a commitment under the Paris Agreement to cut emissions in half by 2030.

That international climate treaty, which the U.S. rejoined in 2021 under President Biden, is intended to limit future global warming to well below 2 degrees

FROM TOP: BYRONWMOORE/DREAMSTIME; MANDEL NGAN/AFP VIA GETTY IMAGES

THE FEDERAL ACTION MARKS THE FIRST MAJOR U.S. LAW EVER TO FOCUS ON CLIMATE CHANGE.

Celsius (3.6 degrees Fahrenheit) — a threshold beyond which risks of severe climate impacts rise precipitously.

The three analyses show the IRA will get the U.S. about two-thirds of the way to fulfilling its Paris Agreement commitment. The act does this through a variety of means. Among them are tax and other incentives designed to coax us into electric vehicles, entice us into installing solar panels, and encourage us to take other steps to cut our carbon footprints. (See the sidebar on this page for more on the IRA's key provisions.)

Other incentives are aimed at industry, including tax credits to accelerate U.S. manufacturing of clean-energy technology. Grants will spur automakers to retool existing facilities to build clean vehicles, and loans are tailored to fund new facilities. To speed development of cutting-edge tech, national labs will get significant new funding.

AS IMPRESSIVE as all of this may seem, it's still not enough to reach the targeted 50 percent cut in greenhouse gas emissions by 2030. Gopal argues that will take not just the carrots of tax and other incentives, but also the sticks of regulation.

Some of those sticks were taken away by the Supreme Court in late June, before the IRA emerged. A ruling by the court's conservative justices in the case of West Virginia v. Environmental Protection Agency curtailed the federal agency's authority to tackle climate change — a big climate story of 2022. "The court took away a couple of tools in the EPA's toolbox," says Jonathan Skinner-Thompson, an associate professor of law at the University of Colorado Boulder. "They are pretty big tools, but definitely not everything."

After the IRA became law, the Biden administration said it would use the tools it still had available to help the U.S. meet its climate commitments. These were to include new regulations on vehicle emissions, power plants, and oil and gas wells.

The bill also incentivizes individual states to slash their own greenhouse gas emissions. And just weeks after it passed in Congress, California certified ambitious legislation that was already in the works before the IRA materialized: By 2035, all new cars sold in the state must be free of fossil-fuel emissions. Because of the Golden State's large population and global influence — plus a GDP of roughly $3.6 trillion to match it — the move toward a zero-carbon transportation system is expected to have a ripple effect.

—TOM YULSMAN

→ **2022 IN BRIEF**

Open Access Journals

This summer, the U.S. Office of Science and Technology Policy announced that academic journals must make federally funded research results available to the public immediately upon publication and for free. The action, set to be fully implemented by 2026, prevents publishers from placing these studies behind embargoes or paywalls. In doing so, it removes a long-standing barrier blocking researchers and the public from emerging findings in scientific fields.

Consumer Incentives and Credits in the IRA

- **A tax credit** of up to $7,500 toward the purchase of an electric vehicle, depending on your income and what you buy (with some incentivizing terms and conditions, such as that vehicles must be assembled in North America). If you're in the market for a used EV, you can claim a tax credit of $4,000 or 30 percent of the vehicle's value, whichever is lower — if the vehicle is at least 2 years old and you meet certain conditions.

ANATOLIY_GLEB/SHUTTERSTOCK

- **Tax credits** to help homeowners install clean and efficient energy technologies such as solar panels for electricity. Depending on your circumstances, you may be able to subtract 30 percent of the cost of these investments from your federal taxes. More modest steps for making the home more comfortable and energy efficient are also incentivized. For example: up to $600 off your taxes for installing energy-efficient windows.

- **Outright grants** for consumers who meet income requirements to help them make energy-saving retrofits to their homes. The greater the energy savings, the higher the rebate, up to a possible maximum of $8,000 per household.

HOME OWNERS CAN SUBTRACT $600 OFF THEIR TAXES FOR INSTALLING ENERGY-EFFICIENT WINDOWS.

- **Significant assistance** for those most at risk from climate change, including $3 billion for grants and technical support to help disadvantaged communities craft responses to climate and air pollution. Billions of dollars more are available to help low-income and disadvantaged communities install or benefit from zero-emission technologies, such as rooftop solar panels. —T.Y.

DECAPOD CRUSTACEANS include crabs, lobsters, crayfish, prawns and many other shellfish.

U.K. RECOGNIZES LOBSTER SENTIENCE

A new animal-welfare law raises the bar for experimenting on decapod crustaceans.

LAST SPRING, the U.K. passed the Animal Welfare (Sentience) Act 2022, marking the first time that animals were declared sentient by British law. The legislation recognized the rights of vertebrate animals such as mammals, birds, reptiles and fish, plus famously intelligent invertebrates like the octopus. While some protections already existed for those creatures, the new act unexpectedly added decapod crustaceans to the mix, including lobsters, crabs and shrimp.

The decision to include decapods as sentient animals was founded on the research of biologist Robert Elwood, who has demonstrated over the past decade that these creatures exhibit "responses consistent with the idea of pain." The professor emeritus at Queen's University Belfast says it's impossible to definitively prove how an animal (or person) feels. But in his experiments, prawns rubbed their antennae after exposure to irritants, while hermit crabs abandoned protective shelters — and even their own shells — to avoid shocks. In short, they acted like they were in pain and learned to evade its source.

The new British legislation — which mirrors laws in Spain, parts of Australia, and other regions — means that scientists experimenting on lobsters and crabs will likely need an ethical committee to approve of their work and consider the animals' well-being. But all decapods in the U.K. aren't out of hot water just yet.

"Curiously, it's still legal to boil a lobster even though the law has been passed recognizing sentience," Elwood says.

That's because the seafood industry is governed by different regulations. Any future changes to those seafood laws, however, will have to consider decapod sentience. "I am guessing

Panama Protects Nature's "Right to Exist"

Crustaceans are not the only creatures that gained legal protections in 2022. In February, Panama passed legislation recognizing the rights of nature itself. The change was spurred by recent fieldwork in the country by marine conservation biologist Callie Veelenturf.

The new law recognizes that "natural entities have an intrinsic value … [and] a specific right to exist," says Constanza Prieto Figelist, the Latin American legal director at the nonprofit Earth Law Center, who helped draft the legislation. Essentially, this means judges must weigh the rights of land developers against the rights (and associated protections) of nature to thrive, and "find a way to harmonize these rights."

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Panama Canal
Chorrera
Balboa
Bay of Panama

Panama now joins dozens of countries with similar laws. Ecuador became the first to include the rights of nature in its constitution in 2008. And places like New Zealand and Bangladesh have declared personhood for rivers.

Prieto Figelist says these laws "invite us to switch our relationship with nature and see all the natural entities in a different way. We're all part of the same system, and we have to live like a family." — KATE GOLEMBIEWSKI

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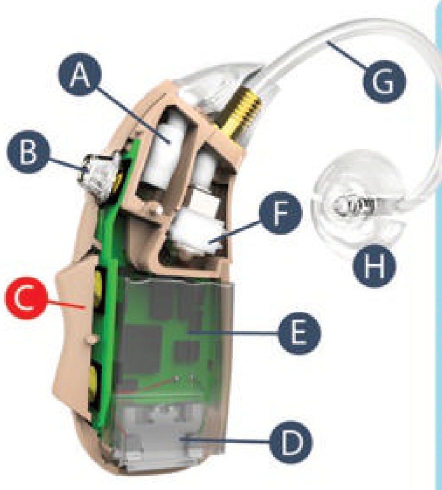

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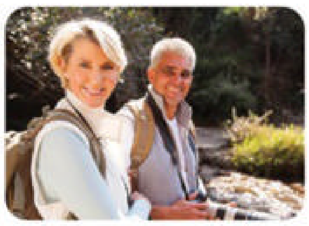

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that things will change," Elwood adds.

WHILE HUMANE treatment of crustaceans in kitchens may not be the law of the land, some chefs have already embraced kinder methods of preparation — rather than boiling them alive, which is standard practice to avoid the spread of bacteria that multiply soon after they die. Nigel Bloxham, the owner of the Crab House Cafe in Weymouth, England, is an early adopter of an invention called the CrustaStun. The device zaps lobsters and crabs with a lethal electric shock, knocking them out in less than a second just before cooking them.

Bloxham says he considers giving the shellfish a swift death the right thing to do, but he's noted an added advantage: "It definitely produces a better product." He's given fellow chefs a blind taste-test of stunned versus traditionally cooked crabs, and "people picked out the stunned crab every time." He suspects the difference in taste is linked with the effects of stress on the animals' muscles. "If I dropped you into boiling hot water, you'd tense up trying to get out," he muses.

In your own kitchen, you can still treat shellfish more humanely without shelling out thousands of dollars for a CrustaStun. Putting them in the freezer for three or four hours, where they fall asleep before eventually freezing to death, is "probably the most humane way I can think of" for home chefs to dispatch their lobsters, says Bloxham. It's almost certainly better than boiling them alive, and also helps eliminate any harmful bacteria.

— KATE GOLEMBIEWSKI

ANY FUTURE CHANGES TO LAWS REGULATING SEAFOOD WILL HAVE TO CONSIDER DECAPOD SENTIENCE.

A NEW SOLUTION TO AN "IMPOSSIBLE" MATH PROBLEM

HAVE MATHEMATICIANS FINALLY SQUARED THE CIRCLE?

Geometry students are taught that squaring the circle — using a compass and straightedge to draw a square with the same area as a given circle — is impossible. But in February, a trio of mathematicians who couldn't resist an impossible challenge presented the closest solution yet for the problem.

Squaring the circle has a history of failed attempts dating back at least to the ancient Greeks. And in 1882, French mathematician Carl Louis Ferdinand von Lindemann proved that pi is transcendental, which means, among other things, that it's impossible to draw a line of that length. Since the area of a circle depends on pi and the area of a square doesn't, a solution was provably impossible.

But what if you abandon the compass and straightedge? Nearly a century ago, mathematicians asked whether it was possible to break a circle into pieces that could be reassembled into a square of the same area, with no compass or straightedge involved. Then in 1989, Hungarian mathematician Miklòs Laczkovich proved that it was theoretically possible, but the pieces would be so complicated as to be unmeasurable.

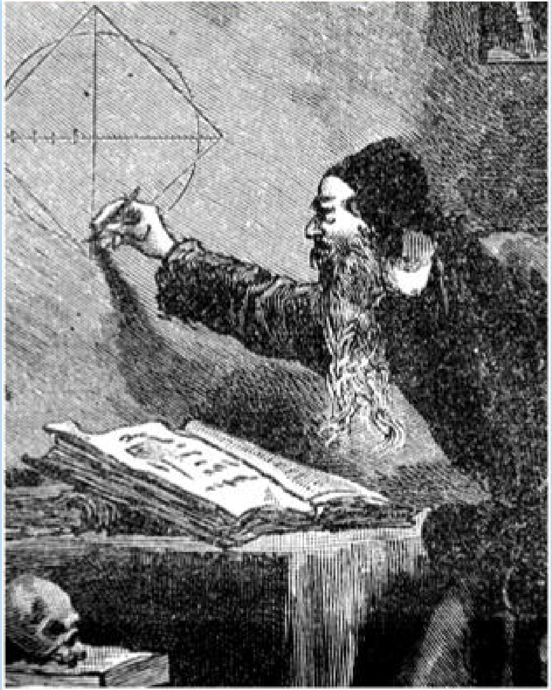
The newly developed method describes a set of simple rules — simple for mathematical recipes, anyway — for this ridiculously complicated jigsaw puzzle. While it builds on previous attempts to solve the problem, it's the first version to describe pieces that, in theory, can be drawn. (Not by hand, but by a computer.)

"We had these two different goals," says mathematician Jonathan Noel of the University of Victoria, British Columbia. One was to improve the algorithm used to generate pieces, and "the other was to get these pieces that you can understand, visually." Noel collaborated on the proof with fellow mathematicians Oleg Pikhurko and András Máthé, both of the University of Warwick in the U.K.

Even with the mathematicians' new rules and a powerful enough computer, it's an understatement to say that drawing the pieces won't be easy. The new algorithm requires about 10^{200} pieces; for comparison, physicists estimate that the universe contains about 10^{80} atoms.

Pikhurko says he hopes to reduce the number of pieces. "I think you can attack that and bring it down, significantly," he says. "But it would need some extra work."

— STEPHEN ORNES



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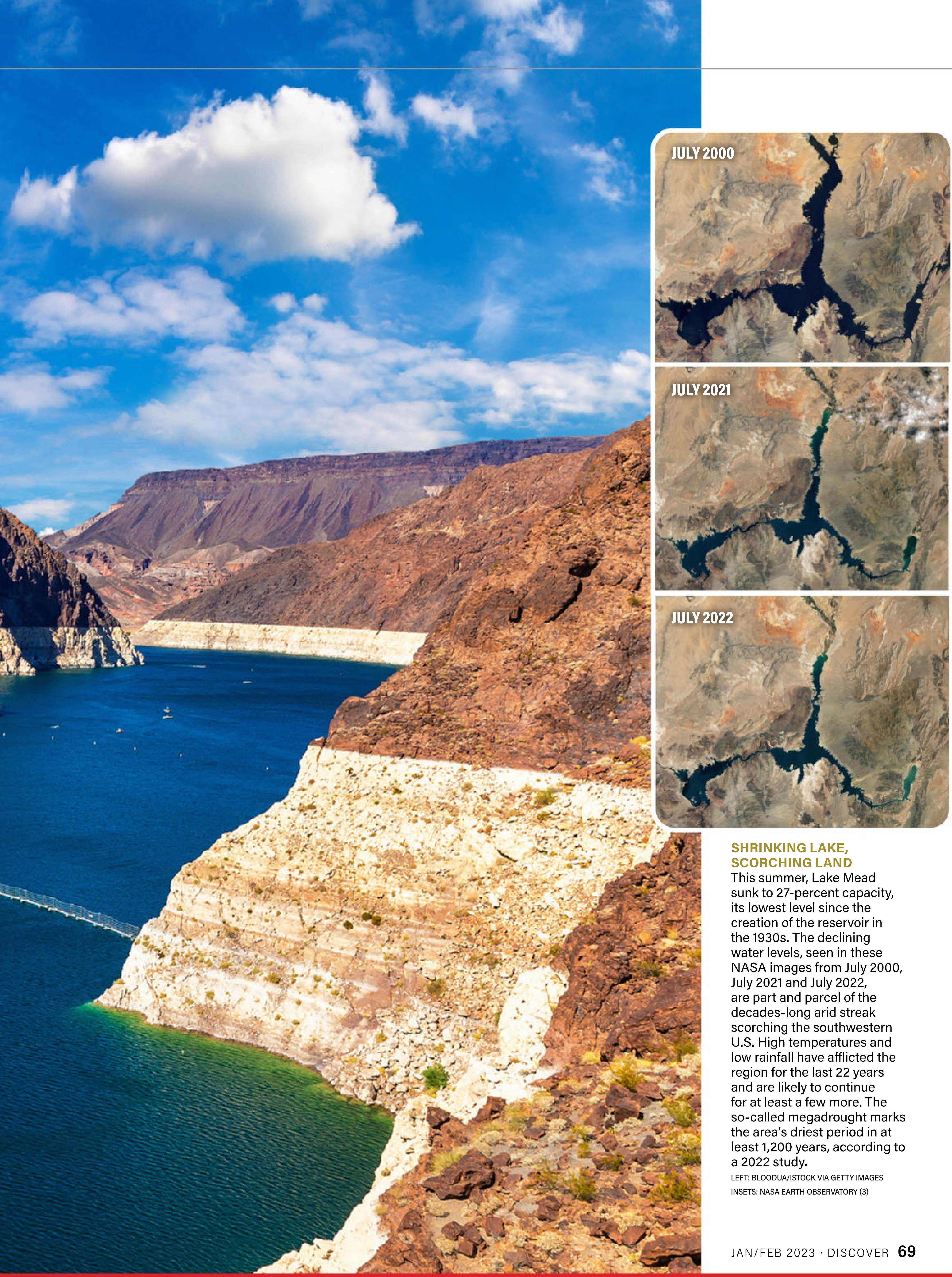


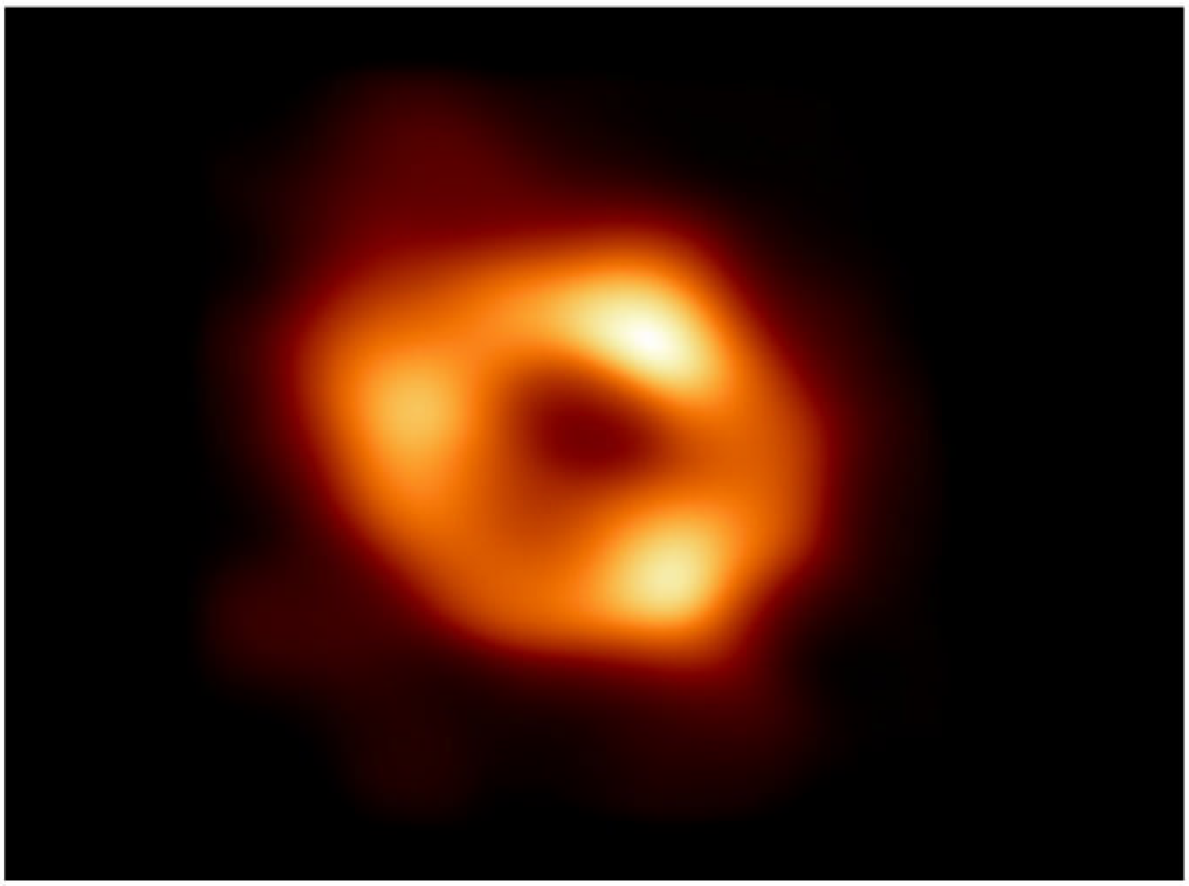
SHRINKING LAKE, SCORCHING LAND This summer, Lake Mead sunk to 27-percent capacity, its lowest level since the creation of the reservoir in the 1930s. The declining water levels, seen in these NASA images from July 2000, July 2021 and July 2022, are part and parcel of the decades-long arid streak scorching the southwestern U.S. High temperatures and low rainfall have afflicted the region for the last 22 years and are likely to continue for at least a few more. The so-called megadrought marks the area's driest period in at least 1,200 years, according to a 2022 study.

LEFT: BLOODUA/ISTOCK VIA GETTY IMAGES
INSETS: NASA EARTH OBSERVATORY (3)

HISTORIC HEAT

Unprecedented heat waves hit swaths of Europe this summer, accompanied by wildfires, droughts and surges of thousands of excess deaths. Sizing up to be the warmest summer on record for the continent by almost a full degree Fahrenheit, the temperatures shattered previous highs set in the U.K., where scientists say that human-caused climate change increased the likelihood of the waves by 10 times. Taken on the hottest day in U.K. history, this image from July 19 shows one strategy for staying cool: dunking yourself in the fountains of Trafalgar Square.

DAN KITWOOD/GETTY IMAGES NEWS/GETTY IMAGES EUROPE



A SINGULAR IMAGE

Astronomers revealed the first image of the supermassive black hole in our very own galaxy this May. Scientists long suspected that something unseen lurked at the center of the Milky Way, but this image, produced by the Event Horizon Telescope Collaboration, offers the first visual proof that that something is a black hole. Because black holes are completely dark, the photo shows the bright, glowing gas that surrounds the object, known as Sagittarius A*, which contains 4 million times more mass than the Sun.

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Like a picked flower cut from the source, we gradually wilt physically and mentally and become vulnerable to a host of degenerative diseases, that we simply weren't susceptible to in our early adult years.

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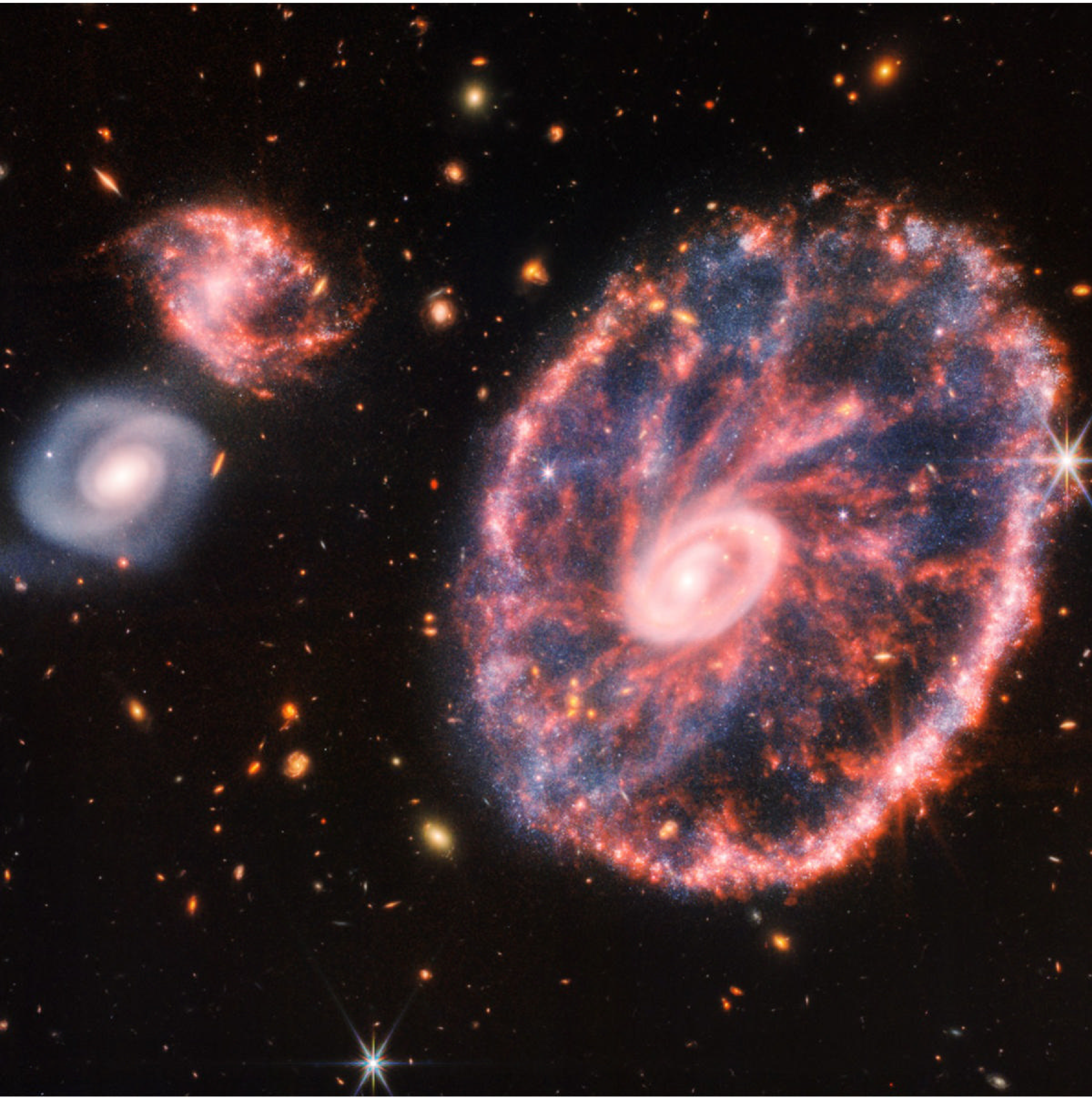
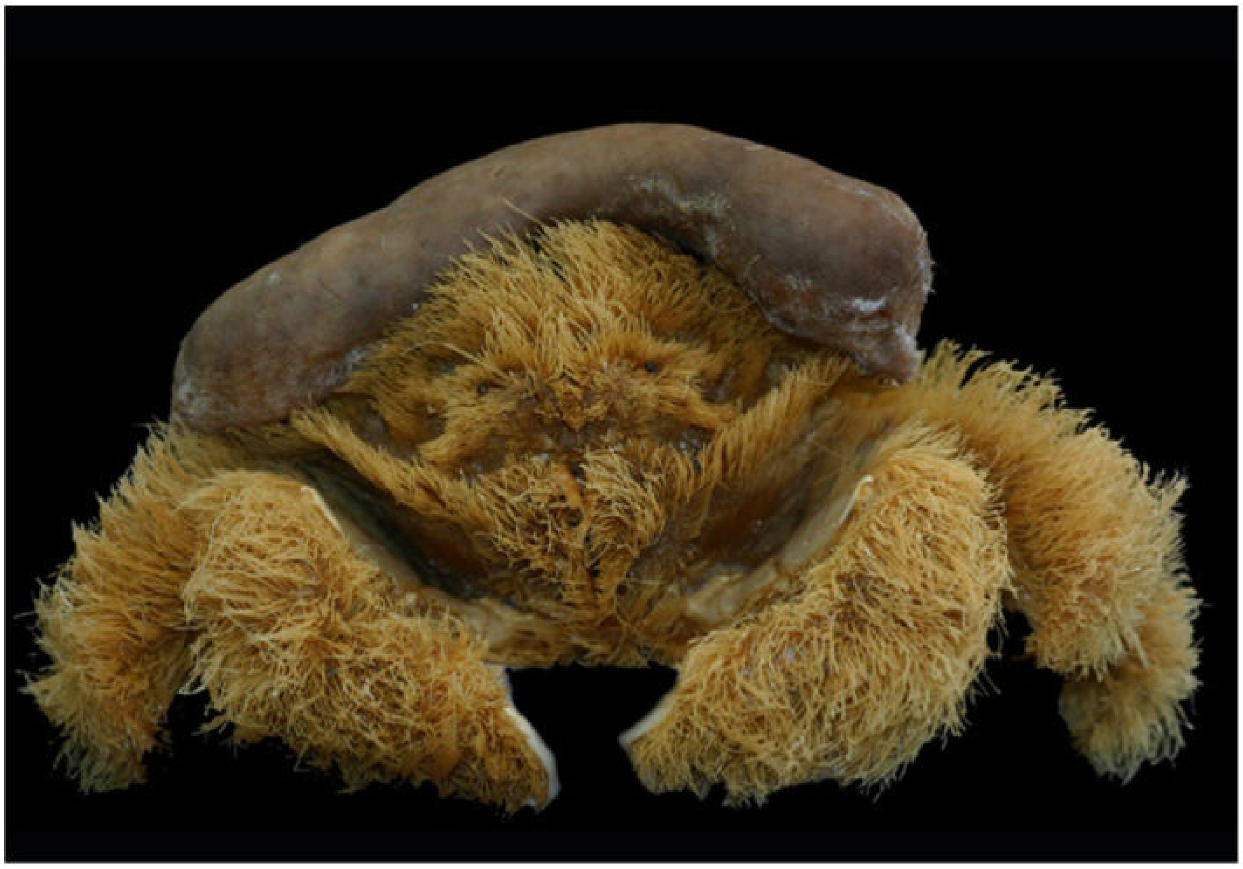


ASTRONOMICAL ACROBATICS

One of the first visuals from the James Webb Space Telescope (see page 28 for the full story), this image captures the Cartwheel Galaxy — a collection of faraway stars, solar systems and interstellar material 500 million light-years away. Formed from the collision of two galaxies, one large and one small, the Cartwheel Galaxy's resulting ring structure testifies to the chaos of our cosmos and provides clues about the transformation of space over time.

NASA, ESA, CSA, STSCI



A FLUFFY FIND

Searching for a crab with a flawless sense of fashion? Look no further. This June, scientists introduced a species of "fluffy" crab, closely related to the hermit crab. The crustaceans actually wear sea sponges and other creatures as a form of camouflage. Though they aren't sure why this new species, named *Lamarckdromia beagle*, is covered in fur, scientists say that the fluff could provide the crabs with an added layer of protection to disguise their legs from predators.

COLIN MCLAY/WESTERN AUSTRALIAN MUSEUM

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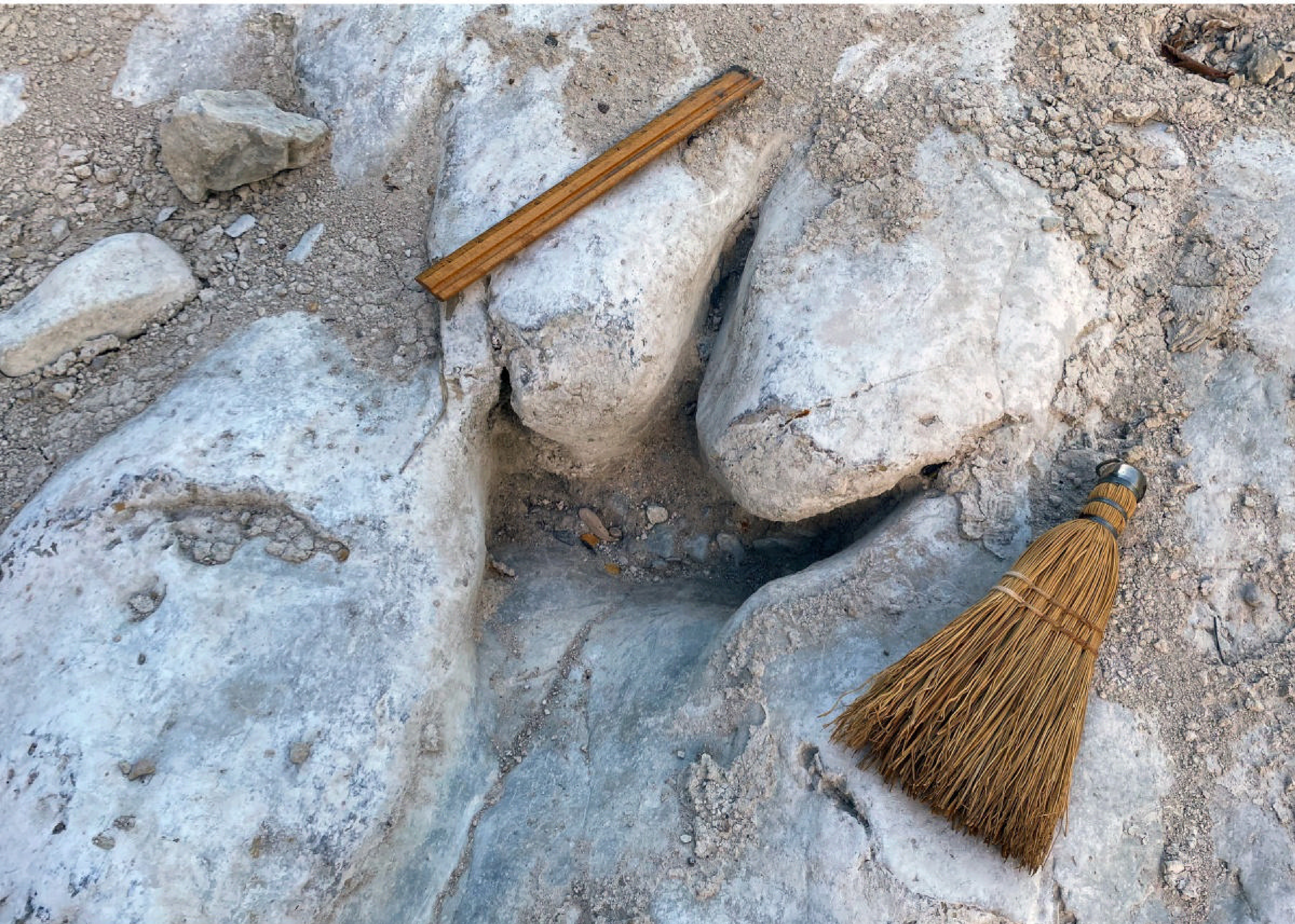

Exposed prints brought droves of visitors this summer to the Lone Ranger Trail (lower left) and B.P. Baker site (top) at Dinosaur Valley State Park, near Glen Rose, Texas.

DINOSAUR TRAIL

Excessive drought uncovered these fossilized dinosaur tracks in central Texas this past August. The 113-million-year-old prints were cleaned, surveyed and recorded by volunteers and staff at multiple sites in Dinosaur Valley State Park, where extreme dryness and heat shrank the Paluxy River over the summer. Research shows these tracks were left by an *Acrocanthosaurus* — a bipedal carnivore that may have been 15 feet tall.

The newly revealed prints are part of five known track sites mapped in the park, including a set left by a *Sauroposeidon proteles*, which stood on four legs at about 60 feet tall. Many of these prints are already back under water. With time, park officials say, sediment will cover and help preserve them long into the future. D

PAUL BAKER/FRIENDS OF DINOSAUR VALLEY (2)

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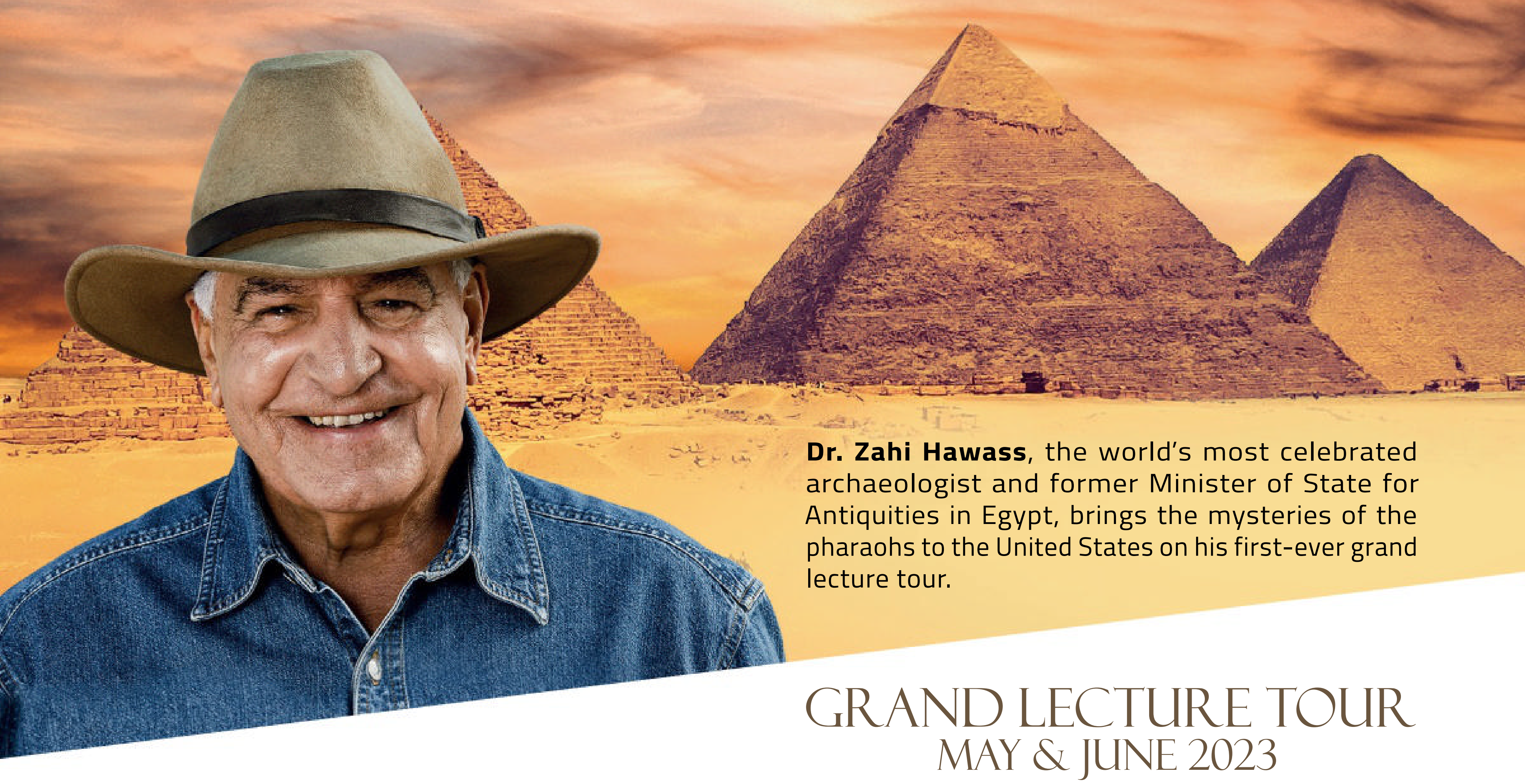

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